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Final Report

Ecological Assessment of a Wetlands Mitigation Bank (Phase III: Restoration Efforts)

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The overall objective for the Tulula Wetlands Mitigation Bank has been to restore the functional and structural characteristics of a mountain stream and the adjacent alluvial wetlands. Specific restoration objectives of this study included: 1) determining the success of stream realignment by evaluating the geomorphology of a new channel before and after water release, 2) evaluating changes in ecosystem structure and function associated with plant community succession in planted and unplanted portions of the floodplain in response to restored hydrology, and 3) evaluating wildlife use of the site in response to changing hydrologic conditions (amphibians) and plant community succession (birds). A meandering channel (8,500 linear feet in length) was constructed across the floodplain and water was released into the new channel in 2001 and 2002. Eight random channel segments were used for measurements of stream geomorphology and after two years of water flow few differences were noted for channel pattern, although changes were observed for cross-sectional areas of riffles and pools. Isolated areas of bank and bed erosion were noted. The hydrology of Tulula has been influenced by the stream restoration, with most notable differences occurring for water-table wells located near the channel. Although the hydrology of Tulula fen was not influenced by stream restoration, the composition of wetland plant communities in the fen was influenced by natural succession. Restoration did influence the composition of some plant communities. For example, restored wetland areas contained fewer species than unrestored areas or restored dry areas, and the species that dominated the restored wet areas were OBL and FACW plants. In addition, production of both vegetative and reproductive stems of a common rush was influenced by restoration and hydrologic change. Recently disturbed areas at Tulula had lower decomposition rates and fewer litter microarthropods compared to older plant communities. Data collected from 1996-2004 indicate that constructed ponds are of higher quality than reference ponds based on physiochemical characteristics, seasonal hydroperiod, and use by resident amphibians. Amphibians rapidly colonized constructed vernal ponds, and the number of species that utilize these as breeding sites averaged about 50% higher than that of reference ponds. The survivorship and output of wood frog and spotted salamander juveniles have declined since pond construction, in part due to the accumulation of predators in ponds, the outbreak of a virus pathogen, and premature pond drying associated with drought. In 2004, bird species richness and relative bird abundance decreased significantly from 2002 levels. Bird species richness decreased 15% and relative bird abundance decreased 52%. Generalist species, such as Song Sparrow and Rufous-Sided Towhee, continued to be the most abundant species, while many Neotropical migrants of conservation concern, including the Golden-winged Warbler, Chestnut-sided Warbler, Hooded Warbler, and Yellow-breasted Chat, declined substantially. The significant declines in bird species richness and relative bird abundance are attributed to habitat changes associated with the flooding of a large proportion of the floodplain as a result of beaver activity. Management intervention is recommended to control the flooding caused by beaver, and to maintain a variety of early-successional habitat types throughout the site.</td></tr>
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EXECUTIVE SUMMARY

Our goal is to document the ecological success of the wetlands at the Tulula Wetlands Mitigation Bank (Graham County) in response to restored hydrology, soils, and vegetation. Our data should provide NCDOT an ecological assessment that may be useful for evaluating other wetland restoration projects located throughout the state. The following objectives provide the framework for a comprehensive ecological assessment of the restored wetlands of Tulula: 1) determine the success of stream realignment by evaluating the geomorphology of the new channel before and after water is introduced, 2) evaluate changes in ecosystem structure and function associated with plant community succession in planted and unplanted portions of the floodplain in response to a higher water table and overbank flooding, and 3) evaluate wildlife use of the site in response to changing hydrologic conditions (amphibians) and plant community succession (birds).

A primary focus of restoration at Tulula was to improve site hydrology. A meandering channel (8,500 linear feet in length) was constructed across the floodplain in five separate sections that were connected in fall 2001 and summer 2002. Eight random channel segments were used for measurements of stream geomorphology, including sinuosity, cross-sectional areas of riffles and pools, bank slope, slope of the water surface, and overall channel configuration. After two years of water flow, differences were noted in certain aspects of channel morphology, and localized areas of erosion were noted with erosion control pins and through increases in the cross-sectional areas of some riffles and pools. However, the overall configuration of the channel was maintained over the two-year period.

The restoration of hydrology at Tulula was evaluated primarily by changes in water-table depth as recorded with a series of electronic and manual wells. Our assumption was that the overall water table of the site would rise after the channel was restored and the drainage ditches were plugged. We found that the hydrology of Tulula was influenced by these restoration efforts, with most changes occurring in water-table wells located near the stream channel. Restoration appeared to have little influence on the hydrology of the fen or of areas located farther from the channel.

Natural succession continues to change the composition of wetland plant communities across Tulula. In 2003, overstory-sized trees were present in a fen that had been characterized by an open canopy in 1994, and there was a dramatic increase in the number of understory-sized trees. The ground layer in this part of the fen also showed an increase in woody species, and a decrease in the importance of plants that require sunlight, such as rushes.

Soil disturbance attributed to restoration activities increased the taxonomic richness in dry areas. In wet areas, restoration combined with a high water table led to colonization by almost almost exclusively OBL and FACW species. Both restoration and the higher water table increased the number and biomass of vegetative stems of *Juncus effusus* (soft rush), and the higher water table increased the number of reproductive stems of this species.

Ten ponds were constructed in 1995-1996 to replace natural breeding sites that were destroyed during golf course construction. Data collected from 1996-2004 indicate that constructed ponds are of higher quality than reference ponds based on physiochemical characteristics, seasonal hydroperiod, and use by resident amphibians. The reference ponds have progressively deteriorated between 1996-2002 with respect to seasonal hydroperiod. In 2002 the majority either did not fill or dried prematurely, resulting in catastrophic mortality of pond populations. In contrast, the hydroperiod of most constructed ponds appears to be ideal for most vernal pond breeders. Seven of 10 ponds underwent seasonal drying in most years, typically in late summer or fall after larvae had metamorphosed. Fish have colonized many ponds since 2002 in association with above normal rainfall, beaver activity, and completion of the final phase of reconstruction.

Amphibians rapidly colonized the constructed ponds, and the number of species that utilize these as breeding sites averaged about 50% higher than that of reference ponds. The survivorship and output of juveniles of two focal species (wood frog; spotted salamander) have declined since pond construction, in part due to the accumulation of predators in ponds, the outbreak of a virus pathogen, and premature pond drying associated with drought. Nonetheless, a small percentage of ponds on site have successfully produced juveniles annually, and populations of both species are being maintained at viable levels.

Results of breeding bird surveys in 2004 indicated that species richness and relative abundance decreased significantly from 2002 levels. Species richness decreased 15%, with 33 species recorded. American Woodcock, Common Grackle, and Eastern Wood-pewee were new species recorded during surveys. Relative bird abundance decreased 52%, with a total of 166 observations. Generalist species, such as Song Sparrow and Rufous-Sided Towhee, continued to be the most abundant species breeding at Tulula, but their numbers decreased dramatically from 2002 levels. The Red-winged Blackbird also continued to be one of the most abundant species, but its numbers held steady relative to 2002 levels. Many Neotropical migrants of conservation concern declined substantially in 2004 including the Golden-winged Warbler, Chestnut-sided Warbler, Hooded Warbler, and Yellow-breasted Chat.

The significant declines in bird species richness and abundance in 2004 are attributed to habitat changes associated with the flooding of a large proportion of the floodplain as a result of beaver activity. Productivity of the habitat for birds at Tulula has decreased and correlates with an increase in the large amounts of area covered with standing water and dominated by rushes and sedges. Management intervention is needed in order to restore the productivity of the habitat for birds. Management objectives should include taking appropriate actions to control the flooding caused by beaver, and maintaining a variety of early-successional habitat types throughout the site.

I. INTRODUCTION

Surface transportation projects such as highway construction often impact wetland resources and cause unavoidable losses of small wetland areas. Increasingly, wetland losses are being mitigated by the creation of "banks" of restored or natural wetlands that are protected from future disturbance. Mitigation banks allow the consolidation of efforts to mitigate for small wetland losses, facilitate advanced planning, and enhance the monitoring and evaluation of mitigation projects (Short 1988). The Tulula Wetland Mitigation Bank was created to offset impacts of highway projects in western North Carolina, particularly in the Little Tennessee River basin (1,158,883 ac) located in Macon, Swain, Graham, Jackson, Clay, and Transylvania Counties. The site was ideal for establishing a mitigation bank in the mountains of North Carolina because of its relatively large size (235 ac) and its need for large-scale restoration.

The Tulula Wetland Mitigation Bank (Tulula) (35°17'N, 83°41'W) is located in Graham County, NC in the floodplain of Tulula Creek, 7.7 miles west of Topton. The site covers approximately 235 ac at an elevation ranging from 2500 to 2800 ft. It is characterized by a relatively large, level floodplain along Tulula Creek, and is bordered by forested uplands and infrequent seepage communities on adjacent slopes. A complete description of vegetative communities at Tulula is found in Moorhead et al. (2001a). Tulula was part of the Nantahala National Forest and owned by the U.S. Forest Service until the mid-1980's, when it was traded to a group of developers for commercial development of a golf course. During construction of the golf course, the bed of Tulula Creek was dredged and channelized and several drainage ditches were dug. Spoil from the drainage ditches and from 11 small golf ponds was spread over portions of the floodplain. A large portion of the floodplain forest was removed during the construction of 18 fairways. About 40% of the wetlands were disturbed by drainage and timber harvest during golf course construction.

Tulula was purchased in 1994 by the North Carolina Department of Transportation (NCDOT) to develop a wetlands mitigation bank. We have collected information on baseline ecological conditions (soils, hydrology, flora, and fauna) and have evaluated restoration activities at the site since 1994 (see www.unca.edu/tulula for details and species lists).

Assessing the success of wetland restoration projects requires an evaluation of ecosystem structure and function. Long-term success is rarely documented, and failure is common for a variety of reasons. Our goal was to document the ecological success of the wetlands at Tulula in response to restored hydrology, soils, and vegetation. Our data should provide NCDOT an ecological assessment that may be useful for evaluating other wetland restoration projects located throughout the state.

The following objectives provide the framework for a comprehensive ecological assessment of the restored wetlands of Tulula: 1) determine the success of stream realignment by evaluating the geomorphology of the new channel before and after water is introduced, 2) following restoration of site hydrology, evaluate changes in ecosystem structure and function associated with plant community succession in the floodplain in response to a higher water table and overbank flooding, and 3) evaluate wildlife use of the site in response to changing hydrologic conditions (amphibians) and plant community succession (birds).

II. RESEARCH METHODS AND RESULTS

Ecological conditions at Tulula have been documented for over ten years by UNCA (see www.unca.edu/tulula, North Carolina Department of Transportation 1997, Rossell et al. 1999, Moorhead et al. 2001a, Moorhead et al. 2001b). Ecological success of wetlands restoration at Tulula has been evaluated by comparing the extensive pre-restoration database to the post-restoration data.

A. Stream Restoration and Hydrology

1. Stream Restoration

A primary focus of restoration at Tulula was to improve site hydrology. A meandering channel (8,500 linear feet in length) was constructed across the floodplain during the winter of 1999/2000. The design of the new channel was based partially on the physical characteristics of a relic channel found primarily at the lower end of the site. The relic channel was used, when practical, as part of the new meandering channel. The channel was re-constructed in 2001/2002 to correct problems associated with longitudinal grade. Common streambank erosion techniques, such as fiber matting, coir fiber rolls, root wads, and live stakes of willow (*Salix* spp.) and silky dogwood (*Cornus amomum*), were installed to improve the short-term stability of the new channel. Four sections of the constructed channel, in the upper and middle portions of the site, were joined together by crossing the dredged channel of Tulula Creek in fall 2001. The fifth section was connected in two stages in May (Section V) and June (Section Va) 2002. The design criteria used to construct the channel are shown in Table 1.

Table 1. Design criteria* for the restored Tulula Creek.

Parameter	Proposed Average Value	Range
Cross-sectional area	18 ft^2	15 – 20 ft^2
Bankfull Width	8.5 ft	8 – 10 ft
Average Depth	2.2 ft	1.6 – 2.9 ft
Maximum Depth	3.6 ft	2.2 – 5.3 ft
Width/Depth Ratio	4	3.1 – 6.3
Meander Wavelength	70 – 80 ft	60 – 100 ft
Sinuosity	1.62	1.44-1.93
Arc Length	50 ft	40 – 70 ft
Radius of Curvature	15 ft	10 – 25 ft
Channel Slope	0.0020	0.0017-0.0022
Rosgen Stream Type**	E5	

*North Carolina Department of Transportation (1997)
**Rosgen (1996)

Methods

A primary objective for restoration efforts at Tulula was to determine the success of stream realignment by evaluating the geomorphology of the new channel before and after water introduction. Eight random channel segments were chosen in the five stream sections that were restored in 2001/2002. Each segment included four to six riffle-pool sequences varying in length from 120 to 180 ft. Each segment began and ended at the top of a riffle and the origin and end were permanently staked with PVC pipe and rebar. These two points served as reference to partially describe the channel geomorphology. A 300-ft measuring tape was secured between the origin pin and the end pin. Beginning at 0 ft (the origin pin), the orthogonal distance from the tape to the left bank, thalweg, and right bank was measured every 6 ft on the 300-ft tape. The data were used to develop overall channel configuration (planview) and to determine sinuosity of channel segments. Data derived from this work included meander wavelength, arc length, belt width, and the radius of curvature.

In each of the eight segments, two riffles and two pools (defined as the middle of a meander) were chosen to establish permanent cross-sections. Bankfull width was determined and channel cross-sections were determined by taking depth measurements every 8 in along a tape that was stretched from the two bank pins of a riffle or pool at the top of each bank. Bank inclination was determined with a clinometer. The cross-section data were used to calculate cross-sectional area, average depth, maximum depth, and the width/depth ratio. Erosion bank pins were installed at the toe or middle of a channel bank at a few riffle and pool cross-sections. The erosion pins were hammered 21 in into the bank walls with 3 in exposed in the channel. Pebble counts, using a modified Wolman method (Rosgen 1996), were conducted for each of the eight stream segments although consistent methodology and results were only available at year 2 of water flow. Pebble counts are used to determine the particle size distribution of channel materials.

The slope of the water surface was surveyed using standard surveying equipment. A 300-ft tape was placed in the channel along the thalweg, with a start point in the channel by the origin pin. The features of each segment (each pool and riffle) were surveyed at the top of the left and right banks and for the thalweg. The water depth was also noted for the thalweg. The top, middle, and bottom of each riffle were surveyed as well as the middle of a meander. The distance of these features were noted from the 300-ft tape lying in the thalweg of the channel. The permanent riffle or pool cross-section pins were also surveyed. Benchmarks for each segment were chosen by using established NCDOT surveying points or by placing a nail in a nearby tree (benchmarks were established throughout the Tulula floodplain by NCDOT during channel construction). Overall slope of the water surface was calculated by dividing the difference in water surface elevation from the origin to the end of the segment (both points representing the top of a riffle) by the total stream distance.

The planview was evaluated before water release and after one year of water flow. The methods used to determine the planview (as described above) are destructive of floodplain vegetation and annual evaluations are not warranted. The other geomorphic characteristics were evaluated before water release and after one and two years of water flow. The goal was to evaluate the geomorphology of the channel annually after the date of water release.

Results and Discussion

The restored channel was constructed as five separate sections (Fig. 1). Eight random channel segments were chosen in the five sections (Fig. 2) to evaluate stream geomorphology over time. Water release began in Section 1 of the restored channel in September 2001. We placed two segments for channel evaluation in Section 1, one each in Sections 2 and 3, two in Section 4, and one each in Sections 5 and 5a. The initial bankfull width and changes in the cross-sectional areas of riffles and pools of the channel segments are listed in Table 1. There was essentially no change in the bankfull widths after two years of water flow and therefore, only the initial bankfull widths are reported in Table 1.

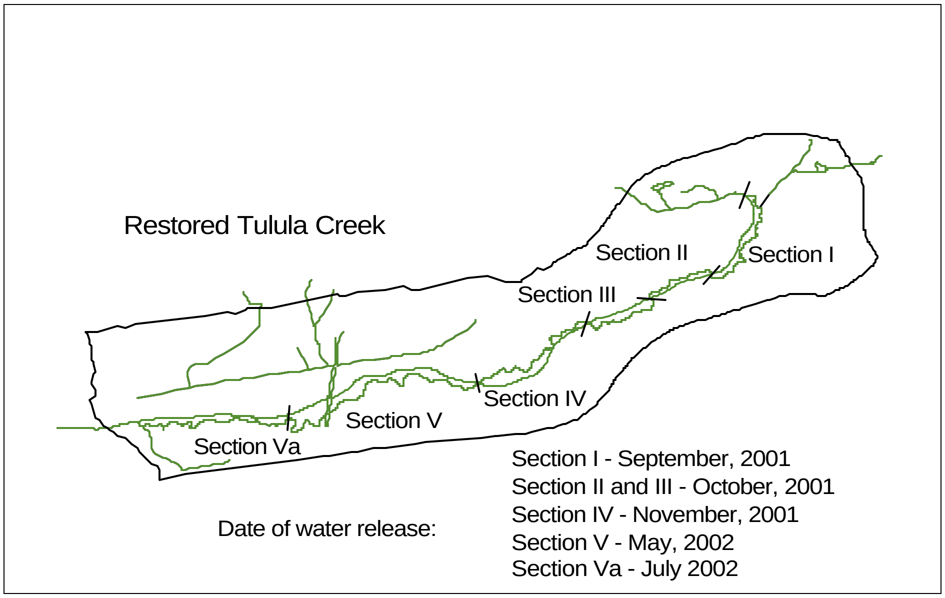


Fig. 1. Restored channel sections of Tulula Creek.

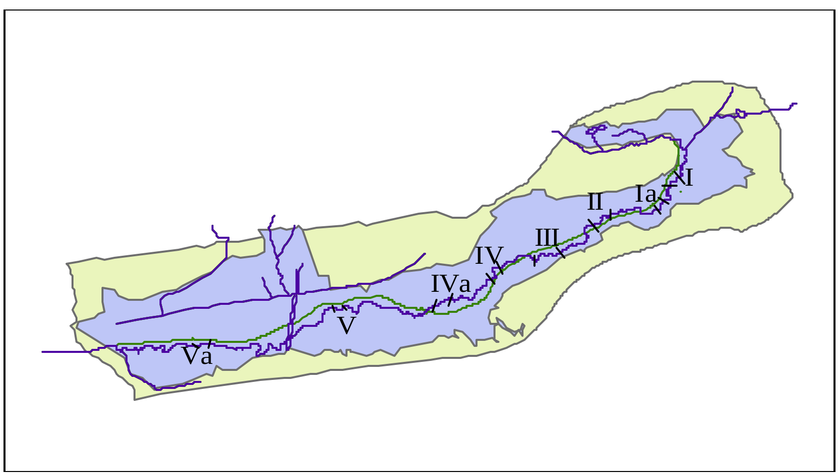


Fig. 2. Approximate locations of stream segments used for channel evaluations.

As anticipated, riffles typically had lower cross-sectional areas and shorter bankfull widths compared to pools (Table 2). Although bankfull widths did not change after two years of water flow, changes in cross-sectional areas were noted for both riffles and pools. The cross-sectional areas of riffles increased after two years of water flow. Nine of 16 riffles had > 10 % increase in cross-sectional area after two years of water flow (Table 3). Ten of 16 pools increased in cross-sectional area but six other pools decreased in cross-sectional area, typically at locations where point bars were forming. The cross section of a stream changes much more rapidly and frequently in meander bends and, therefore, there is more variability in pool cross sections than in riffle cross sections (FISRWG, 1998). A visual representation of riffle and pool cross sections is shown in Appendix A. Changes in cross-sectional area are often used as an indicator of stream channel stability. Increases in cross-sectional area represent areas of stream degradation (sediment erosion) while increases indicate aggradation (sediment deposition) of a stream channel. Changes at Tulula probably represent adjustments of a constructed channel to various flow regimes over the past two years.

Table 2. Bankfull width (ft) and cross-sectional area (ft^2) and of riffles and pools in eight stream segments.

	Bank Full	----------Cross-Sectional Area-------------		
	Width	Initial	One Year	Two Years
Segment I				
Riffle 1	13.58	20.10	18.80	21.93
Pool 1	15.42	33.27	27.93	24.21
Riffle 2	11.81	14.59	13.99	15.69
Pool 2	15.42	26.71	27.57	28.92
Segment IA				
Riffle 1	10.50	13.84	14.42	16.36
Pool 1	10.27	19.07	18.96	19.76
Riffle 2	12.96	19.50	19.86	22.12
Pool 2	12.57	18.94	17.97	18.40
Segment II				
Riffle 1	16.34	19.67	20.34	21.93
Pool 1	16.01	30.26	25.03	27.80
Riffle 2	12.80	13.69	14.81	16.36
Pool 2	14.31	20.29	23.35	24.7
Segment III				
Riffle 1	13.29	18.55	18.25	20.06
Pool 1	18.87	31.27	30.82	32.99
Riffle 2	16.90	23.89	25.44	24.70
Pool 2	17.88	26.88	21.28	22.49

Segment IV				
Riffle 1	12.53	16.14	17.15	17.50
Pool 1	14.08	21.35	24.70	23.33
Riffle 2	12.73	18.91	23.34	22.57
Pool 2	14.57	26.38	27.33	27.59
Segment IVa				
Riffle 1	12.40	12.22	14.66	15.39
Pool 1	13.58	22.29	19.50	21.15
Riffle 2	15.13	19.22	21.89	21.50
Pool 1	13.52	19.71	19.17	21.74
Segment V				
Riffle 1	14.76	17.13	20.51	19.58
Pool 1	16.24	24.08	27.03	24.72
Riffle 2	13.78	15.45	16.70	16.66
Pool 2	16.33	28.32	32.97	33.33
Segment Va				
Riffle 1	9.68	15.24	----	16.98
Pool 1	11.65	18.14	----	19.60
Riffle 2	15.26	18.57	----	19.43
Pool 2	10.04	16.68	----	18.12
Average				
Riffle 1	12.89	16.61	17.73	18.72
Pool 1	14.53	24.97	24.85	24.20
Riffle 2	13.91	17.98	19.43	19.88
Pool 2	14.31	22.99	24.23	24.41

Table 3. Percent change in cross-sectional area of riffles and pools after two years of water flow. Numbers in brackets represent a decrease in cross-sectional area.

Segment	Riffle 1	Pool 1	Riffle 2	Pool 2
I	9.1	(27.2)	7.5	8.3
Ia	18.2	3.6	13.5	(2.8)
II	11.5	(8.1)	19.5	22.0
III	8.1	5.5	3.4	(17.1)
IV	8.3	9.3	19.3	4.6
IVa	25.9	(5.1)	11.9	10.3
V	14.3	2.7	7.8	17.7
Va	11.4	8.1	4.6	8.6
Average	**13.4**	**(1.4)**	**10.9**	**6.4**

The average sinuosity of the restored channel was 1.32 (Table 4), compared to the design sinuosity of 1.62. The slope of the water surface varies for the stream segments and has decreased over two years in four of seven stream segments (Table 4).

Table 4. Sinuosity and slope of the water surface over time.

Segment	Sinuosity	Initial slope	At 1 year	At 2 years
I	1.23	0.0030	0.0036	---
Ia	1.22	0.0024	0.0010	0.0006
II	1.26	0.0022	0.0019	0.0018
III	1.43	0.0028	0.0026	0.0016
IV	1.29	0.0044	0.0047	0.0059
IVa	1.22	0.0022	0.0025	beaver
V	1.32	0.0024	0.0014	0.0018
Va	1.58	---	---	---
Average	1.32	0.0028	0.0025	0.0020

The width/depth (W/D) ratio of riffles was slightly higher than for pools and decreased after two years of water flow (Table 5). The decrease in W/D was a result of slightly higher average and maximum depths of the channel with no increase in bankfull width. A W/D ratio of 12 is a high end value for “E” stream types (Rosgen 1996). The W/D ratio is used to understand the distribution of energy within a channel. If the W/D ratio increases, the hydraulic stress against the banks also increases and bank erosion is accelerated (Rosgen 1996).

Table 5. Width/depth (W/D) ratio and maximum depth (ft) of riffles and pools (represents the average of seven stream segments).

Time	Riffle 1	Pool 1	Riffle 2	Pool 2
Initial W/D	11.4	9.2	11.3	10.0
Two Years W/D	10.0	9.6	10.2	9.5
Initial max depth	2.06	2.97	2.21	2.72
Two years	2.74	3.07	2.88	3.24

Other physical characteristics of the stream segments suggest that the restored channel was not as sinuous as designed. This was reflected in the higher meander wavelengths and radius of curvature and lower belt widths of channel segments (Table 6) as compared with design criteria (Table 1). However, channel configuration has not changed after two years of water flow, suggesting that the geometry of the restored channel was suitable for the various flow conditions that occur in Tulula Creek.

Table 6. Other physical characteristics of selected meanders in each stream segment.

Section	Meander Wavelength (ft)	Arc Length (ft)	Belt Width (ft)	Radius of Curvature (ft)
I	65.6	45.3	42.7	19.4
Ia	68.9	24.3	43.6	10.2
II	95.1	55.8	55.8	23.3
III	98.4	66.3	57.4	21.0
IV	137.8	61.4	77.1	21.3
IVa	75.5	42.7	22.9	24.3
V	75.5	59.1	57.1	22.3
Average	88.3	50.5	50.9	20.3

The cumulative pebble counts of the eight stream segments are shown in Fig. 3. With the exception of stream segment Va, 40 to 70 % of the cumulative pebble counts were found in the silt/clay fraction. Segment Va is the closest representation of the relic channel of Tulula, with minor adjustments made to small portions of the stream bank during stream re-construction. Roughly 10 % of the pebble count was silt/clay in this segment. With the addition of sands, 80 to 98 % of the pebble counts were accounted for in the eight stream segments. The additional stream bed materials consisted of gravel.

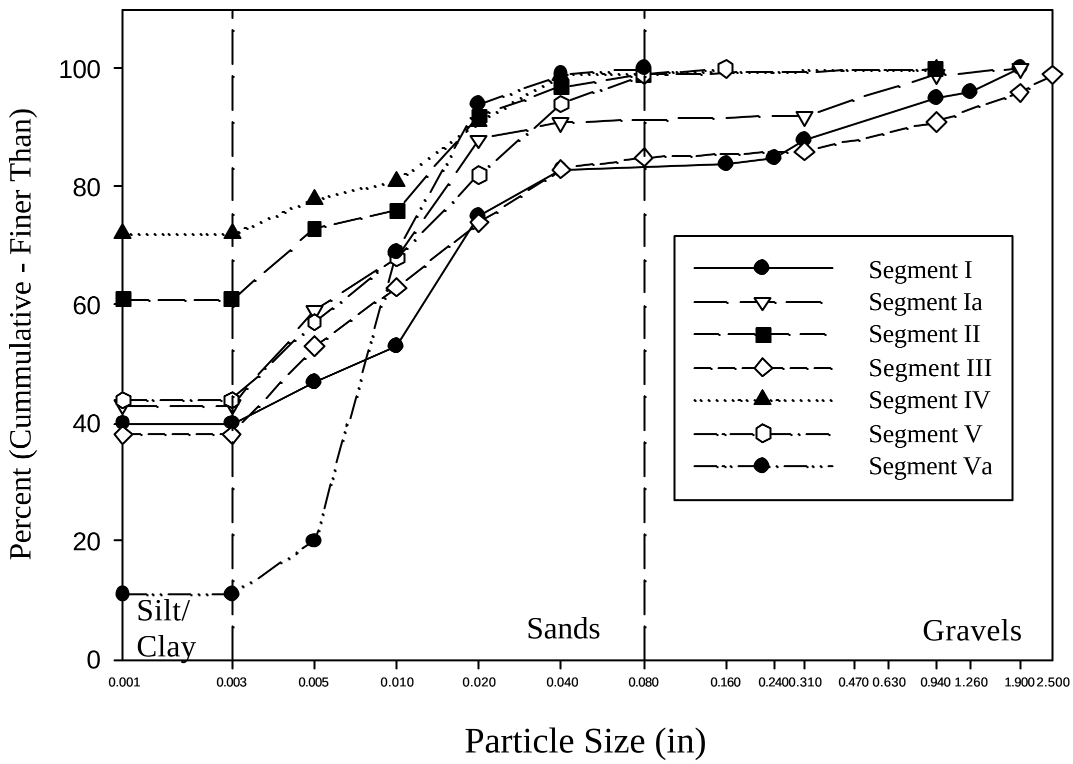


Fig. 3. Cumulative pebble counts of seven stream segments.

Bank inclinations of riffles and pools created for the restored channel were commonly between 20 and 30 degrees (data not shown). Although significant erosion was noted at the bottom of the banks (toe of the bank slope) of riffles and pools (Table 7), overall bank inclinations did not change appreciably after two years of water flow because of the lack of erosion in the middle and upper portions of stream banks. The erosion noted at the bottom of channel banks through erosion control pins can be used to evaluate the lateral stability of a channel. Several points along the re-constructed Tulula channel are at risk of instability based on lateral erosion, most notably the riffle/pool sequence of Section Ia, and to a lesser extent Riffle 2 of Section III and Pool 1 of Section IV. The meander width ratio (meander belt width divided by bankfull channel width) is another indicator of lateral stability. Given the lack of changes in meander belt or bankfull width after two years of water flow, the ratio has not changed, suggesting that the re-constructed channel is fairly stable.

The overall channel configuration has not changed substantially after two years of water flow. However, changes in channel depth have altered the cross-sectional areas of riffles and pools and changed the W/D ratio. Desirable features have formed in the channel, most notably point bars on inside banks of many meanders. Changes in cross section and bank erosion at certain locations suggest that the channel is still adjusting to the flow regimes of Tulula Creek. Minor adjustments can be made for areas that appear to have unstable banks or stream bed conditions.

Table 7. Erosion of channel banks after two years of water flow, based on erosion control pins.

Segment	Feature	Location	Erosion (inches)
I	Pool 1	Toe	2.02
I	Riffle 2	Toe	5.26
Ia	Riffle 1	Toe	11.26
Ia	Pool 1	Toe	11.98
Ia	Riffle 2	Toe	3.85
II	Pool 1	Toe	1.62
II	Pool 1	Middle	2.02
II	Riffle 2	Toe	0.16
III	Riffle 1	Toe	0.40
III	Riffle 2	Toe	5.66
IV	Riffle 1	Toe	0.40
IV	Pool 1	Toe	4.86
IV	Pool 1	Middle	0.81
IV	Riffle 2	Toe	0.40

2. Hydrology

Concurrent with construction of the new channel, drainage ditches were blocked and filled. The expectation was that re-constructing a meandering channel would decrease water velocity, which, when coupled with blocked drainage ditches, would raise the level of the water table across the floodplain and allow for more frequent overbank flooding. One of our objectives was to determine if site restoration improved the overall site hydrology. Electronic water table wells were installed in July 2000 along transects that were perpendicular to the new channel (Fig 4). In addition, site hydrology has been monitored for over ten years with a series of manual water table wells and piezometers (Fig. 5). Many of the manual wells and all of the piezometers are located in a 4-ha floodplain/fen complex that serves as a reference area for several UNCA research projects. We have documented seasonal patterns of water-table elevation and vertical hydraulic gradient in this area and determined the influence of hillslopes and drought on fen hydrology (Moorhead 2001, Moorhead 2003).

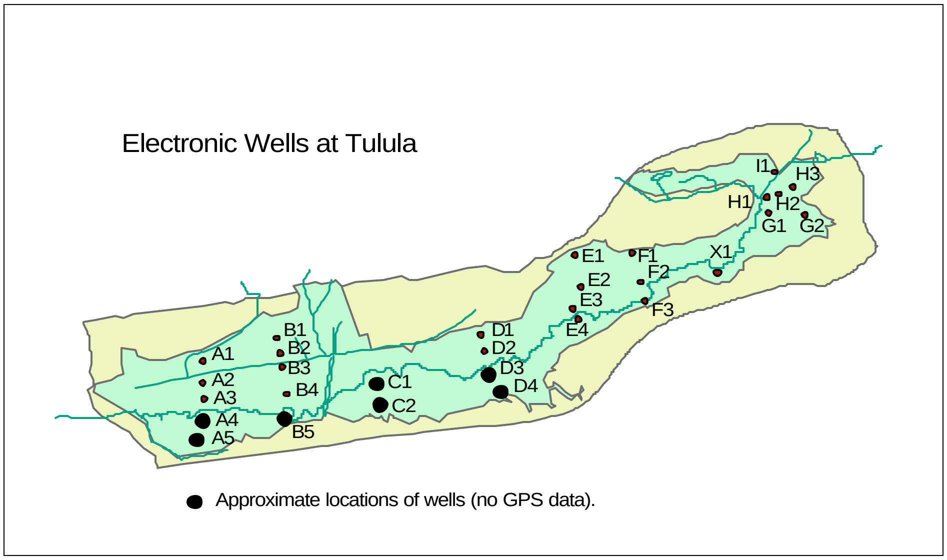


Fig 4. Transects and individual electronic wells used to assess site hydrology of the restored stream channel. See Appendix A for daily water-table levels of wells.

Methods

Both electronic and manual water-table wells were used to determine if the floodplain water table was higher because of the new channel and blocked drainage ditches. Methods of installation are described in Moorhead et al. (2001a). The manual wells were read two to four times a month. The electronic wells were programmed to record the water-table depth on a daily basis. The data for both types of wells were converted to monthly averages to compare the pre- and post-restoration conditions. The monthly data were then used to construct hydrographs over a one-year period that coincided with the release of water in the various stream sections. For example, the months of September through the following August were used for developing hydrographs for electronic or manual wells in stream section I (water release in September, 2001). Differences between the average monthly pre- and post-restoration water-table levels were analyzed with a Student's t-test in Microsoft Excel.

Results and Discussion

The success of hydrology restoration at Tulula, like many wetland sites, will be determined primarily by changes in water-table depth. The assumption was that after the channel was restored and the drainage ditches were plugged, the overall water table of the site would rise. The electronic wells were also used by NCDOT to determine the success of wetland hydrology as determined by the Section 404 permitting system of the U.S. Army Corps of Engineers (at least 12 consecutive days of inundation or saturation during the growing season; North Carolina Department of Transportation, 2003).

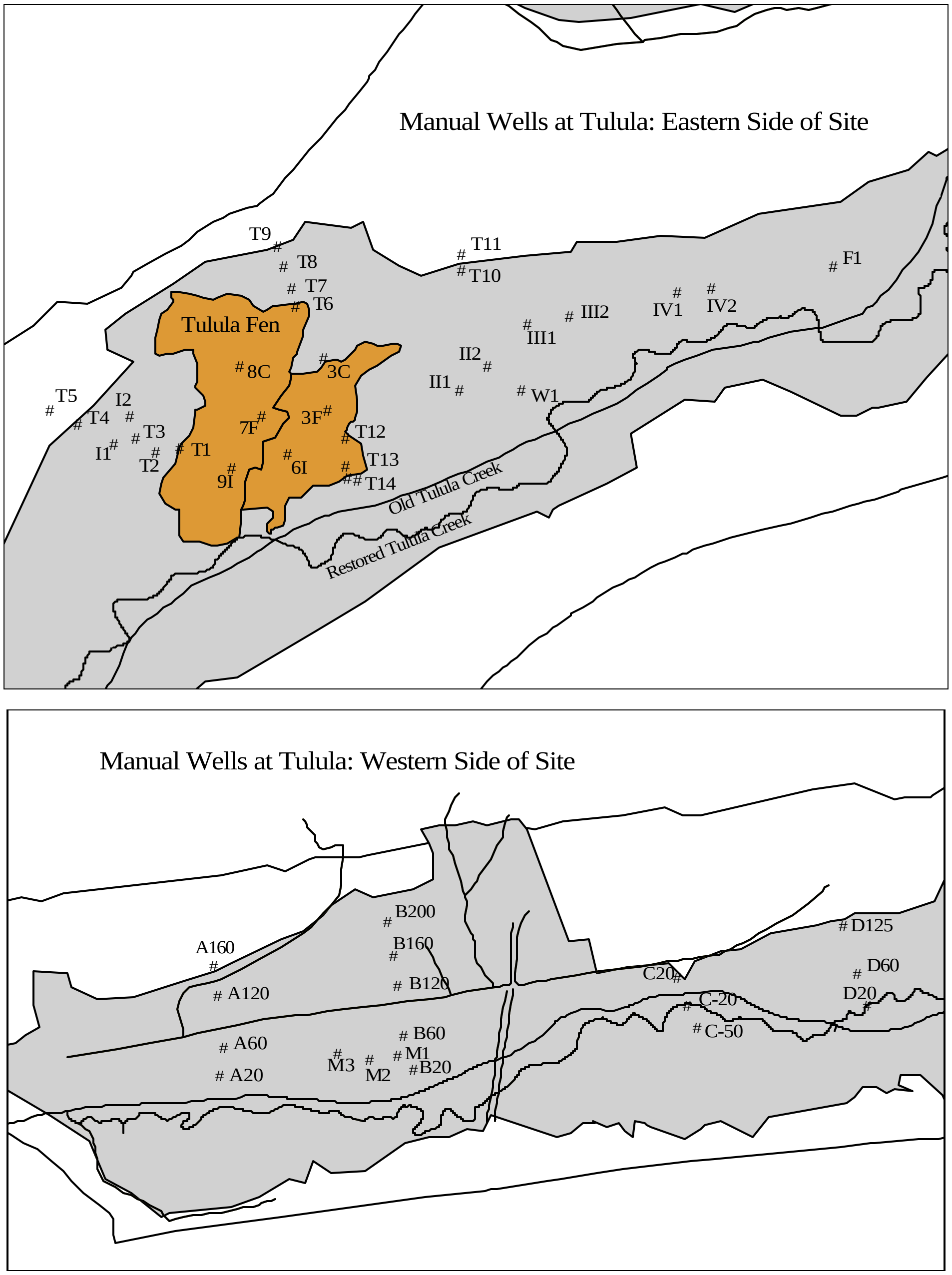


Fig. 5. Location of manual wells at Tulula. Wells A160, A120, B200, B160, B120, and D20 were destroyed during site restoration and were not replaced.

The electronic wells were installed in July 2000 and one or two years of pre-restoration data were compared to two years of post-restoration data, depending on the date of water release into the various stream sections. The data from individual wells are organized by stream section. As an example, the daily water-table graphs of electronic well X1 (in stream section I) and the monthly averages are shown in Fig.6. A comparison of the pre- and post-restoration monthly averages provides an easier visual interpretation of changes in water table depth due to restoration. The remaining monthly averages of water-table graphs of electronic wells are found in Appendix B.

A rise in the water table was viewed as an improvement in site hydrology. For example, the restoration of the stream channel improved the hydrology at X1. In stream section I, the water table increased in the following electronic wells: H3, G1, G2, and X1 (Appendix B1). It was not as consistent at H2, and although there appeared to be an overall raise at I1, the restoration of Tulula Creek and hydrology did not improve site hydrology at I1 to meet the requirements of wetland hydrology for the permitting process. Water-table graphs from electronic wells in stream section II and III showed a consistent raise in the water table after restoration for electronic wells E1, E2, E3, and F2 (Appendix B2). There was no consistent water table rise for D-transect electronic wells associated with stream section IV (Appendix B3). In section V and Va, the water rose after restoration for electronic wells C1, C2, B1, B3, B4, B5, and A3. However, several of these wells were influenced by the flooding of the lower end of the site by beaver dams. In particular, C1, C2, B4, B5, and A3 are located near or in areas of flooded conditions from beaver dams.

Data from some of the manual wells have been collected since 1994 (locations of wells shown in Fig. 3). Monthly averages of water-table depth were calculated for seven years of pre-restoration data and two years of post-restoration data. The figures illustrating the pre- and post-restoration water-table data from individual manual wells are found in Appendix C. There are seven years of pre-restoration data including three years of drought conditions (July 1998 through fall 2001 (Moorhead 2003). The data from manual wells provide a more comprehensive view of site hydrology, given the varied conditions of annual precipitation before restoration, given the three drought years and the higher than average annual precipitation during June 1994 through 1997.

At the eastern side of the site, the depth of the water table of Tulula fen (wells 3C, 3F, 6I, 9I, 7F, and 8C; Appendix C1a) and the floodplain adjacent to it (wells II1 and 2, III1 and 2, IV1 and 2; Appendix C1b) showed few statistical differences before and after restoration of site hydrology. The statistical differences were noted more often in summer months, during periods of plant transpiration. Based on manual wells, the water table of Tulula was improved (higher) for wells located near the stream channel (F1, T13, T14), with little or no improvement documented for wells located farther from the channel (T1, T2, T3, T4, T5, T6, T7, T8, T9, T10, T11, T12; Appendix C1c). Collecting water-table data over the next few years and comparing pre- and post-restoration water-table levels will provide a more comprehensive view of how site restoration has changed the hydrology of Tulula wetlands.

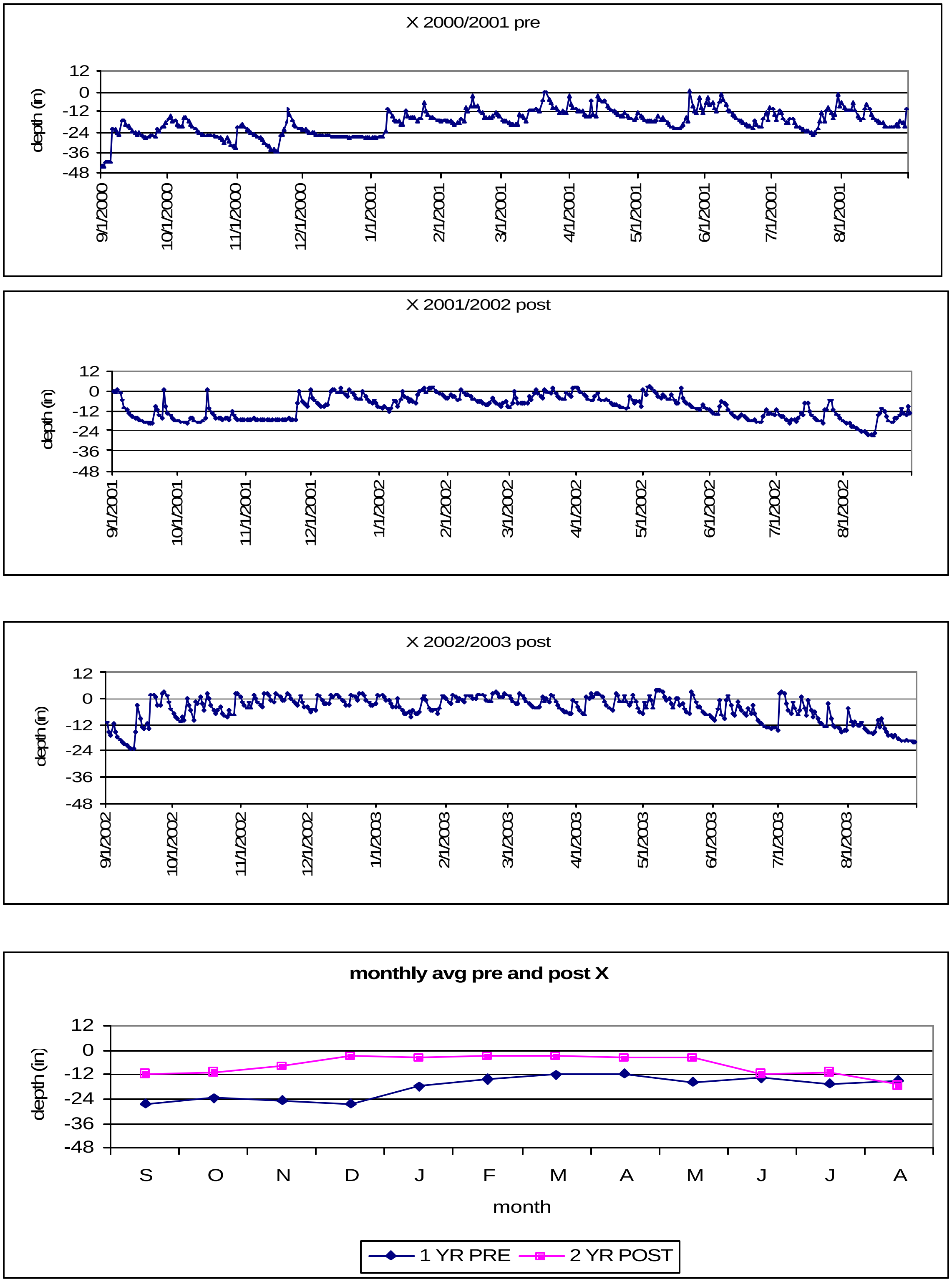


Fig. 6. The daily water table and monthly averages for electronic well X1. Statistical differences ($P < 0.05$) were noted for the monthly averages of all months except June. Depth of "0" represents the surface of the soil.

The main concern of NCDOT will be whether the wetlands of the Tulula floodplain have the appropriate hydrology to meet permit conditions. The data required for this determination are collected with the electronic wells and analyzed on a yearly basis (see North Carolina Department of Transportation, 2003 for examples). A more interesting ecological question is how the overall hydrology has changed at Tulula with site restoration. The manual wells will provide more information for this question since they were installed in 1994.

B. Vegetation responses to restoration

One of our objectives for restoring wetlands in the Tulula floodplain has been to monitor the response of native wetland plant communities. We have been monitoring the community composition of an intact fen since 1994, and during this funding cycle, we were able to examine the community post-restoration. We also sought to gain a better understanding of the relationship between wetland plants and environmental factors such as hydrology. We used *Juncus effusus* L. (soft rush), which is an easily recognizable and widespread species in the Tulula floodplain (and elsewhere), as an indicator species to evaluate the effects of hydrology and restoration on plant growth and reproduction. In a previous seed bank study at Tulula, Rossell and Wells (1999) reported that *Juncus* spp. dominated the wetland seed bank, especially in an early successional area of the fen. Our objectives were to determine whether the growth and reproduction of *Juncus effusus* were enhanced by wetland restoration, and how overall species richness responded to restoration.

1. Plant growth responses to restoration and hydrologic regime

Methods

We used data from groundwater wells to select four sites at Tulula: an undisturbed wet area, a nearby undisturbed drier area, a restored wet area, and a nearby restored drier area. At each site, we delineated a 50m x 10m study area in relatively uniform plant communities. Within each of the four study areas, we established 20, 0.25-m^2 quadrats at randomly selected points (using a table of random numbers). Our only criterion was that all quadrats contained *Juncus effusus*. If a randomly selected quadrat did not contain *J. effusus*, it was rejected, and another random quadrat was selected.

In July 2003, we surveyed the plant associates of *Juncus effusus* in each study area. All plants occurring in all 80 quadrats were identified to species, and coverage within the quadrat was visually estimated. We obtained the Region 2 (southeastern United States) wetland indicator status for each species by consulting U.S. Fish and Wildlife Service (1996) and U.S. Department of Agriculture (2001). Wetland indicator status categories describe wetland affinities as follows: obligate wetland plants (OBL) occur in wetlands >99% of the time, facultative wetland plants (FACW) occur in wetlands 67-99% of the time, facultative plants (FAC) occur in wetlands 34-66% of the time, facultative upland plants (FACU) occur in wetlands 1-33% of the time, and upland plants (UPL) occur in wetlands <1% of the time.

In early September 2003, we used shears to harvest all aboveground plant material within each quadrat. Plant material was placed on tarps, then sorted into four categories: vegetative stems of *Juncus effusus*, reproductive stems of *Juncus effusus*, non-*Juncus effusus* herbaceous plants, and woody plants. All plant material was placed into paper bags, air-dried to constant weight in a warm dry building, and weighed. The numbers of *Juncus effusus* vegetative and reproductive stems were counted. All *Juncus effusus* inflorescences were clipped off of reproductive stems, and weighed separately.

We performed an analysis of variance (ANOVA) to determine the effects of restoration status (restored vs. unrestored) and hydrology (wet vs. dry) on the following variables: number and biomass of vegetative *Juncus effusus* stems, number and biomass of reproductive *Juncus effusus* stems, biomass of *Juncus effusus* inflorescences, biomass of non-*Juncus effusus* vegetation, and biomass of woody vegetation. Statistical Analysis Systems was used for all analyses (SAS 2001).

Results and Discussion

Juncus effusus (a FACW species), although present in all quadrats, never occupied more than 25% of the area of any one quadrat. In half to three-fourths of all quadrats, *Juncus effusus* occupied <5% of the area of the quadrat. Clearly, although a consistent presence in all of our quadrats, *Juncus effusus* was not a dominant species overall. It had many associate species that were reflected in our calculations of taxonomic richness.

Taxonomic richness was greatest in the restored dry area (48 taxa), and lowest in the restored wet area (17 taxa). Richness was intermediate in the unrestored dry (33 taxa) and unrestored wet (37 taxa) areas (Table 8). OBL and FACW species made up the greatest percentage of the flora in the restored wet area (93.3%), and the smallest percentage in the unrestored dry area (55.5%) (Table 9). The percentage of OBL and FACW species in the unrestored wet (67.7%) and in the restored dry areas (60.5%) were similar.

Table 8. Taxa and wetland indicator status of plants occurring in 0.25-m^2 quadrats in four study areas at Tulula.

Taxon	Area: Unrest. Dry	Unrest. Wet	Restored Dry	Restored Wet	Wetland indicator status
Acalypha rhomboidea Raf.			x		FAC
Acer rubrum L.		X	x		FAC
Agalinis purpurea (L.) Pennell			x		OBL
Agrimonia parviflora Ait.		X			FAC
Agrostis sp.			x		FACW
Alnus serrulata (Ait.) Willd.				X	FACW
Ambrosia artemisiifolia L.	x	X	x		FACU
Ambrosia trifida L.		X			FAC
Andropogon virginicus L.	x				FAC
Apios americana Medicus	x	X	x		FACW
Aster novae-angliae L.	x	X	x		NA
Aster pilosus Willd.	x		x		NA
Bidens frondosa L.			x		FACW
Boehmeria cylindrica (L.) Sw.		X			FACW
Campanula aparinoides Pursh.	x				OBL
Carex annectens (Bickn.) Bickn.		X			FACW
Carex debilis Michx.	x				FACW
Carex festucacea Willd.		X			FACW
Carex lurida Wahl.	x	X	x	X	OBL
Carex scoparia Schkuhr ex. Willd.	x	X	x		FACW
Carex sp. 1	x				NA
Carex sp. 2		X			NA
Cassia fasciculata Michx.			x		NA
Clematis virginiana L.	x	X	x		FAC
Cuscuta campestris Yuncker				X	NA
Cyperus strigosus L.			x		FACW
Desmodium cuspidatum (Willd.) Loudon	x				NA
Dicanthelium clandestinum (L.) Gould	x	X	x		FACW
Dicanthelium ensifolium	x	X	x		NA
Eleocharis obtusa (Willd.) Schultes		X			OBL
Eleocharis tenuis (Willd.) Schultes		X			FACW
Epilobium ciliatum Raf.				X	NA
Erigeron annuus (L.) Pers.			x		FACU
Erigeron philadelphicus L.			x		FAC
Eupatorium fistulosum Barratt			x		FAC
Eupatorium perfoliatum L.			x		FACW
Galium tinctorium L.		X	x	X	FACW
Grass sp.1			x		NA
Grass sp.3			x		NA
Grass sp.4			x		NA

Holcus lanatus L.	x	X			FACU
Hypericum mutilum L.	x	X	x	X	FACW
Impatiens capensis Meerb.	x	X	x	X	FACW
Juncus acuminatus Michx.		X	x	X	OBL
Juncus brevicaudatus (Engelm.)Fern.				X	OBL
Juncus effusus L.	x	X	x	X	FACW
Juncus tenuis Willd.	x	X	x		FAC
Lespedeza cuneata (Dumont) G.Don			x		NA
Liriodendron tulipifera L.			x		FAC
Lobelia puberula Michx.			x		FACW
Ludwigia alternifolia L.		X	x		OBL
Mimulus ringens L.		X	x	X	OBL
Onoclea sensibilis L.		X			FACW
Osmunda cinnamomea L.		X			FACW
Oxalis sp.	x		x		UPL
Oxalis stricta L.		X			UPL
Panicum virgatum L.		X			FAC
Persicaria hydropiper L.	x	X	x	X	OBL
Persicaria sagittatum L.	x	X	x	X	OBL
Persicaria spp.	x				NA
Potentilla simplex Michx.	x		x		FACU
Prunella vulgaris L.	x				FAC
Pycnanthemum verticillatum (Michx.) Pers.	x	X			UPL
Rhynchospora glomerata (L.) Vahl.			x		OBL
Rosa palustris Marsh.	x	X			OBL
Rubus argutus Link	x	X	x	X	FACU
Rubus hispidus L.	x				FACW
Sagittaria latifolia Willd.				X	OBL
Sambucus canadensis L.	x		x		FACW
Scirpus expansus Fern.		X		X	OBL
Scirpus polyphyllus Vahl.			x		OBL
Solidago gigantea Aiton	x	X	x		FACW
Solidago rugosa Miller	x		x		FAC
Sparganium americanum Nutt.				X	OBL
Trifolium campestre Schreb.			x		NA
Trifolium repens L.			x		FACU
Vernonia noveboracensis (L.) Michx.	x		x		FAC
Viola sp.			x		NA

Table 9. Contribution of each wetland indicator status (as a percent of all vegetation in 0.25-m^2 quadrats) in four study areas at Tulula (for plants with a known indicator status).

	Unrestored area		Restored area	
Wetland Indicator Status	Dry	Wet	Dry	Wet
OBL	18.5	26.5	23.7	60.0
FACW	37.0	41.2	36.8	33.3
FAC	22.2	17.6	23.7	0
FACU	14.8	8.8	13.2	6.7
UPL	7.4	5.9	2.6	0

The results of our ANOVA showed that vegetative *Juncus* stems were more numerous (P<0.0001), as well as heavier (P=0.004) in unrestored areas (Table 10). Similarly, non-*Juncus* herbs were heavier in unrestored areas (P=0.002) (Table 11). Neither the number nor the biomass of reproductive *Juncus* stems were influenced by restoration (P>0.05).

When water table was considered, vegetative *Juncus* stems were more numerous (P=0.007) as well as heavier (P=0.002) in wet areas (Table 12). Reproductive *Juncus* stems were more numerous (P=0.015), but not heavier (P=0.064), in wet areas. The biomass of non-*Juncus* herbs was lower in wet areas than in dry areas (P<0.0001)(Table 13**).**

Table 10. Effects of restoration on vegetative growth and reproduction of *Juncus effusus*. Within columns, means followed by the same letter do not differ significantly (P>0.05).

	Vegetative *Juncus* stems		Reproductive *Juncus* stems		*Juncus* inflorescences
Treatment	No.	Biomass (g)	No.	Biomass (g)	Biomass (g)
Unrestored	190.0a	23.4a	15.5a	8.4a	1.6a
Restored	69.0b	13.6b	11.5a	6.2a	1.2a

Table 11. Effects of restoration on biomass of plants occurring with *Juncus effusus* in 0.25-m^2 quadrats. Within columns, means followed by the same letter do not differ significantly (P>0.05).

Treatment	Herbaceous plants (non-*Juncus*) (g)	Woody plants
Unrestored	50.3b	78.5a
Restored	82.4a	39.7a

Table 12. Effects of hydrology on vegetative growth and reproduction of *Juncus effusus*. Within columns, means followed by the same letter do not differ significantly (P>0.05).

	Vegetative *Juncus* stems		Reproductive *Juncus* stems		*Juncus* inflorescences
Treatment	No.	Biomass (g)	No.	Biomass (g)	Biomass (g)
Wet	156.2a	23.8a	19.7a	9.5a	1.8a
Dry	102.8b	13.1b	7.4b	4.3a	0.8a

In summary, the disturbance that is inherently part of restoration activities clearly benefited the growth of non-*Juncus* herbaceous plants, perhaps by opening up the canopy and minimizing competition for light. In contrast, *Juncus effusus* was more numerous and heavier in undisturbed areas, perhaps because it is less competitive than the associated flora. A high water table benefited *Juncus effusus* (a FACW species) more than the associated flora, however, and stimulated the production of reproductive stems, ensuring the continued presence of *Juncus effusus* in the seed bank over the long term. Overall, plant taxonomic richness was greatest in restored dry areas, but lowest in restored wet areas, implying that a high water table inhibited many species and favored the establishment of OBL and FACW plants.

Table 13. Effects of hydrology on biomass of plants occurring with *Juncus effusus* in 0.25-m^2 quadrats. Within columns, means followed by the same letter do not differ significantly (P>0.05).

Treatment	Herbaceous plants (non-*Juncus*) (g)	Woody plants (g)
Wet	41.0b	98.5a
Dry	92.1a	36.3a

2. Vegetation dynamics in Tulula Fen and adjacent floodplain

To determine the effects of wetland restoration on plant communities in an intact fen at Tulula, we examined the community composition of open and closed canopy areas of fen and adjacent disturbed floodplain. The vegetation in these areas was inventoried twice prior to restoration (1994 and 2001). We repeated the inventory of each area in July 2003, in order to evaluate any changes that might have arisen as a result of the altered hydrology at the site.

Methods

We inventoried vegetation using the protocol established in 1994, and a grid of 120 yd^2 plots that was laid out throughout the fen in 1994. Within this grid, 20 plots were randomly selected in an area with a closed canopy, and 20 plots in an area with an open canopy. In each 32.8 ft x 32.8 ft plot, we identified all overstory trees with a DBH > 4 in, and measured its DBH. In nested 13.1 ft x 13.1 ft plots, we identified all understory trees and shrubs with a DBH of 0.8 – 4.0 in, and measured their DBH. In nested 3.3 ft x 3.3 ft quadrats, we identified all herbaceous plants and woody seedlings (DBH < 0.8 in), and visually estimated their percent cover. In an adjacent floodplain that was disturbed by the golf course developers for the purpose of creating a golf fairway, 6, 65.6 ft x 98.4 ft plots were established in 1994. Within each of these 6 plots, overstory trees were inventoried in an 59 ft x 59 ft plot, and understory trees were inventoried in a 23 ft x 23 ft plot (these plot sizes were selected so that the total area inventoried in the floodplain was consistent with the total area inventoried in each area of the fen). Within each of the 6 plots, we inventoried herbaceous and woody vegetation in 4, 3.3 ft x 3.3 ft quadrats (N=24).

We obtained the Region 2 (southeastern United States) wetland indicator status for all woody species by consulting U.S. Fish and Wildlife Service (1996) and U.S. Department of Agriculture (2001). Importance values (IV's) were calculated for all overstory and understory woody species, and for six groups of herbs/woody seedlings (ferns, forbs, grasses, rushes, sedges, and woody seedlings). For the overstory and understory species, IV's were calculated based on density, basal area, and frequency of occurrence. For the six groups of herbs/woody seedlings, IV's were calculated based on percent cover and frequency of occurrence.

Results and Discussion

During the nine years of this study, the number of red maples in the overstory of the closed canopy fen increased from 104 in 1994, to 123 in 2003 (Table 14). However, the overall importance of red maple (*Acer rubrum* L.) declined, from IV=93 in 1994, to IV=86 in 2003 (Table 15). At the same time, the importance of white pine (*Pinus strobus* L.) increased, from IV=3 in 1994, to IV=11 in 2003. Conversely, in the open canopy area of the fen, the importance of red maple increased during this 9-year period. In 1994 there were no overstory trees (DBH > 4.0 in) in the open canopy area of the fen. By 2003, 14 overstory-sized red maples were present in this area.

Table 14. Total number of overstory trees of each species in 20, 10x10-m^2 plots.

	Closed Fen			Open Fen			Floodplain		
Species	1994	2001	2003	1994	2001	2003	1994	2001	2003
Acer rubrum L.	104	109	123	-	4	14	-	-	-
Amelanchier sp.	1	-	-	-	-	-	-	-	-
Ilex opaca Ait.	1	1	1	-	-	-	-	-	-
Malus angustifolia (Ait.) Michx.	-	2	1	-	-	-	-	-	-
Pinus strobus L.	2	5	11	-	-	-	-	-	-
Total	108	117	136	-	4	14	-	-	-

Table 15. Importance values for overstory trees in 10x10-m^2 plots.

	Wetland	Closed Fen			Open Fen			Floodplain		
Species	Status	1994	2001	2003	1994	2001	2003	1994	2001	2003
Acer rubrum	FAC	93.2	88.6	86.0	-	100	100	-	-	-
Amelanchier sp.	-	1.7	-	-	-	-	-	-	-	-
Ilex opaca	FAC	1.7	1.8	1.4	-	-	-	-	-	-
Malus angustifolia	-	-	2.1	1.4	-	-	-	-	-	-
Pinus strobus	FACU	3.4	7.5	11.2	-	-	-	-	-	-

In the understory of the closed canopy fen, neither the total number of stems (Table 16) nor the importance of any species changed appreciably between 1994 and 2003 (Table 17). However, in the open canopy fen, the total number of stems of understory-sized trees (DBH 0.8 - 4.0 in**)** increased dramatically from 121 stems in 1994, to 234 stems in 2003 (Table 16). Most of this increase was due to the number of red maple and tag alder (*Alnus serrulata* (Ait.) Willd.) stems that entered this size class. The overall importance of red maple declined from IV=89 in 1994, to IV=71 in 2003, primarily because the taxonomic richness in this area increased from 3 understory-sized species in 1994, to 12 understory-sized species in 2003 (Table 17).

Table 16. Total number of understory trees of each species in 20, 4x4-m^2 plots.

Species	Closed Fen 1994	Closed Fen 2001	Closed Fen 2003	Open Fen 1994	Open Fen 2001	Open Fen 2003	Floodplain 1994	Floodplain 2001	Floodplain 2003
Acer rubrum L.	73	77	72	111	157	174	-	6	1
Alnus serrulata (Ait.) Willd.	3	4	1	8	23	33	-	6	15
Amelanchier laevis Wiegand	-	-	-	-	2	2	-	-	-
Aralia spinosa L.	-	-	-	-	1	1	-	-	-
Aronia arbutifolia (L.) Ell.	-	1	-	-	7	3	-	-	-
Aronia melanocarpa (Michx.)Ell.	-	-	-	-	5	-	-	-	-
Ilex opaca Ait.	-	5	4	-	-	1	-	-	-
Ilex verticillata (L.)Gray	3	5	6	-	1	-	-	-	-
Liriodendron tulipifera L.	-	-	-	-	1	1	-	-	-
Malus angustifolia (Ait.)Michx.	2	1	-	-	-	-	-	-	-
Nyssa sylvatica Marsh.	5	5	6	-	2	4	-	-	-
Oxydendrum arboreum (L.)DC	1	2	2	-	-	-	-	-	-
Pinus strobus L.	4	7	7	2	4	1	-	-	1
Prunus serotina Ehrhart	-	-	-	-	1	1	-	-	-
Rhus copallina L.	-	-	-	-	-	-	-	1	-
Rosa palustris Marsh.	-	-	-	-	1	-	-	-	-
Salix sericea Marsh.	-	-	-	-	2	12	-	-	-
Sambucus canadensis L.	1	-	-	-	4	1	-	2	-
Vaccinium corymbosum L.	-	1	1	-	-	-	-	-	-
Viburnum cassinoides L.	9	6	6	-	-	-	-	-	-
Total	101	114	105	121	211	234	-	15	17

In the ground-layer community, the closed canopy fen showed an increasing dominance by ferns (mostly cinnamon fern, *Osmunda cinnamomea* L.) over the nine years of this study (IV=32.5 in 1994, IV=48.5 in 2003) (Tables 18 and 19). The open canopy fen showed a decline in the importance of rushes (IV=10.2 in 1994, IV= 0 in 2003) and an increase in the importance of woody plants (IV=19.5 in 1994, IV=29.2 in 2003). Since many rushes flourish in open, sunny areas or those with only partial shade (Thunhorst 1993), it is likely that the shading created during natural succession at Tulula will largely eliminate rushes from this area of the fen. Woody plants increased even more in the adjacent disturbed floodplain (IV=19.3 in 1994, IV=40.2 in 2003).

Table 17. Importance values for understory trees in 4x4-m^2 plots.

Species	Wetland Status	Closed Fen 1994	Closed Fen 2001	Closed Fen 2003	Open Fen 1994	Open Fen 2001	Open Fen 2003	Floodplain 1994	Floodplain 2001	Floodplain 2003
Acer rubrum	FAC	69.8	65.3	65.6	89.0	67.9	70.9	-	41.6	13.4
Alnus serrulata	FACW	3.4	3.0	1.4	10.6	7.8	9.2	-	34.2	73.3
Amelanchier laevis	-	-	-	-	-	1.2	1.5	-	-	-
Aralia spinosa	FAC	-	-	-	-	1.0	1.4	-	-	-
Aronia arbutifolia	FACW	-	1.2	-	-	5.5	2.9	-	-	-
Aronia melanocarpa	FAC	-	-	-	-	2.6	-	-	-	-
Ilex opaca	FAC	-	4.2	4.6	-	-	1.4	-	-	-
Ilex verticillata	FACW	3.4	4.2	5.3	-	1.0	-	-	-	-
Liriodendron tulipifera	FAC	-	-	-	-	1.0	1.4	-	-	-
Malus angustifolia	-	1.9	1.2	-	-	-	-	-	-	-
Nyssa sylvatica	FAC	5.3	4.2	6.4	-	2.1	4.3	-	-	-
Oxydendrum arbreum	UPL	1.5	2.4	2.9	-	-	-	-	-	-
Pinus strobus	FACU	6.3	8.5	8.0	3.3	3.3	1.4	-	-	13.3
Prunus serotina	FACU	-	-	-	-	1.0	1.4	-	-	-
Rhus copallina	FACU	-	-	-	-	-	-	-	9.9	-
Rosa palustris	OBL	-	-	-	-	1.0	-	-	-	-
Salix sericea	OBL	-	-	-	-	1.2	3.0	-	-	-
Sambucus canadensis	FACW	1.5	-	-	-	3.3	1.4	-	14.3	-
Vaccinium corymbosum	FACW	-	1.2	1.4	-	-	-	-	-	-
Viburnum cassinoides	FACW	6.9	4.6	4.2	-	-	-	-	-	-

Table 18. Mean percent cover of each plant type in 1x1-m^2 quadrats.

Plant type	Closed Fen 1994	Closed Fen 2001	Closed Fen 2003	Open Fen 1994	Open Fen 2001	Open Fen 2003	Floodplain 1994	Floodplain 2001	Floodplain 2003
Fern	21.8	12.2	15.2	8.9	11.0	6.4	0.3	1.8	3.1
Forb	0.9	0.5	0.2	4.8	4.3	2.7	29.7	10.4	14.7
Grass	0.4	0.2	0.1	12.6	4.5	2.8	23.3	3.0	6.5
Rush	0.2	0	0	4.6	0.1	0	6.2	1.0	0.8
Sedge	12.0	6.4	2.9	32.9	21.0	18.8	2.9	20.4	3.1
Woody	19.5	13.6	4.9	15.6	23.3	17.1	14.7	41.8	42.5

The number of dead trees in the closed canopy region of the fen increased somewhat during our study for understory-sized trees. In 1994, we recorded 7 dead stems in this size class, compared with 13 dead stems in 2001 (we counted 11 dead stems in 2003, but some of those could have been standing since 2001). Because the site restoration was not complete by 2001 and the hydrology had not been altered in this part of the floodplain, the most likely causes of death for these stems are dry conditions at the site during the 1990's, shading, and/or disease.

Table 19. Importance values for plant types in 1x1-m^2 quadrats.

	Closed Fen			Open Fen			Floodplain		
Plant type	1994	2001	2003	1994	2001	2003	1994	2001	2003
Fern	32.5	33.8	48.5	11.4	14.9	13.6	1.9	3.4	5.6
Forb	7.4	3.8	3.6	11.3	12.1	11.5	29.4	17.0	20.6
Grass	3.6	3.3	2.6	17.2	13.9	13.6	25.3	11.4	14.3
Rush	1.5	0	0	10.2	1.2	0	12.9	7.4	8.3
Sedge	24.1	23.3	18.9	30.4	28.0	32.1	11.2	23.4	11.0
Woody	31.0	35.8	26.5	19.5	29.8	29.2	19.3	37.5	40.2

In summary, the changes in the fen reflect what might be expected due to natural succession, but not to changes in hydrology due to site restoration. The closed canopy fen continues to be dominated by red maple, although the overstory shows a small increase in white pine. Given the overall lack of disturbance in recent years, the open fen is reverting to a forested canopy, and is dominated by red maple. Heliophytic herbaceous plants like rushes are decreasing throughout the fen, while shade-tolerant herbs such as ferns are increasing.

3. Survival of commercial red maple stock

Methods

During the winter of 1995, we planted 77 red maple seedlings in each of three of the 65.6 ft x 98.4 ft plots in the disturbed floodplain (N=231). We re-inventoried these red maple saplings during fall 2003, so that we could compare their survival to that determined in several previous (pre-restoration) years.

Results and Discussion

Survival of the commercial red maple seedlings appears to have declined somewhat during 2003 (Table 20). The number of surviving saplings had been relatively steady from 1995 until 2002 (some of the discrepancies in the results of each year's survey are likely due to the fact that there are now thousands of naturally-regenerating red maple saplings in this floodplain, and it is sometimes difficult to determine whether a saplings was planted, or has regenerated on its own). Survival during 2003 was 10% less than it has been since 2000.

It is premature to pinpoint the factor(s) that are responsible for the decreased survival of these saplings during 2003, but one of the most significant is likely competition from the aggressive growth of blackberries (*Rubus argutus* Link) and other tall shrubs in some areas of this floodplain. In these areas, the planted red maple seedlings have been overtopped by other vegetation. Other factors that have influenced the survival of the planted saplings over the last few years have included browsing by deer, and the spraying of herbicides in the vicinity of a large powerline that crosses the floodplain (the herbicides were sprayed by the local power company, in an effort to control vegetation under the powerline).

Table 20. Survival of 231 commercial red maple seedlings planted in Tulula floodplain during winter 1995.

Year	Survival (%)
1995	77
1996	71
2000	76
2001	81
2002	76
2003	66

Despite the reduced survival of planted saplings, naturally-regenerating red maple saplings continue to flourish in the Tulula floodplain. This trend is documented by Warren et al. (2004), who conducted comprehensive surveys of red maple regeneration across this floodplain in 1994 and 2001. They reported that red maple readily colonized wetland habitats, with a post-disturbance recruitment window lasting at least twice as long as that reported for terrestrial habitats.

C. Effects of Restoration on Decomposition and Soil Microfauna

Decomposition is a primary ecosystem function in the recycling of nutrients (Swift et al. 1979, Seastedt 1984), and is influenced by factors such as soil nutrients, temperature, composition of plant material, and composition and activity of soil fauna. Although many studies have examined decomposition in upland hardwood communities in the southern Appalachians (see Reynolds et al. 2003), and some research has focused on decomposition in cypress-gum wetlands (Battle and Golliday 2001) and playa wetlands in the southern Great Plains (Anderson and Smith 2002), little is known about decomposition in wetlands of the southern Appalachians.

The vital role of microarthropods in decomposition and nutrient cycling has been long established (Swift et al. 1979), but research in wetland systems appears to be minimal. Braccia and Batzer (2001) examined invertebrates associated with woody debris in a southeastern floodplain wetland, but their study did not include decomposition. Indeed, these authors emphasized that terrestrial wetland fauna have been overlooked, and they found that non-aquatic (including Acari and Collembola) rather than aquatic arthropods, were the most significant component of overall community structure. We conclude, therefore, that the present research, combining decomposition studies with microarthropod data, is not only useful but ground-breaking. In this section, we report on decomposition and microarthropod studies conducted in five plant communities at Tulula, and relate these data to soil pH and organic matter.

1. Decomposition

Methods

Six plots, co-located with water table wells, were established in each of five plant community types at Tulula. Plant communities used were the red maple forest (RM), open (OF) and closed fen (CF), floodplain(FP), and the former fairway – a disturbed alluvial bottomland forest (DA). Twelve fiber-glass screen litter bags, 6 x 6” with mesh size of 1/16 “, containing known weights of air-dried *Acer rubrum* (red maple) leaves were placed in each plot in a 4 x 3 grid. The fresh-fallen leaves were collected in October, 2002, and the litter bags placed in the field in January, 2003. Each litterbag was anchored with a survey flag and lightly covered with surrounding litter**.** One litterbag was removed from each plot every other month, beginning in March, 2003 and continuing through May of 2004. Bags were transported in zip-loc bags to the lab, and the litter content weighed after microarthropod extraction. Percent mass of the remaining litter was calculated. Tukey’s Studentized Range (HSD) Test, (SAS version 8), was used for statistical analysis.

Results and Discussion

After 17 months in the field, the percent mass of litter remaining averaged 50% for the RM site to 54.8% for the FP site (Fig. 7). The percent mass remaining in RM, CF, and OF was not significantly different, nor was the mass remaining in FP, DA, OF, and CF. However, decomposition was significantly greater in RM than in DA and FP. This indicates to us that in the least disturbed site, which has an intact canopy and least disturbed soil, the important process of decomposition occurs most readily. Therefore, one would assume that the ensuing process of nutrient cycling would also occur most readily in the least disturbed, RM site. Since there is no significant difference in percent mass remaining between the FP and the OF, we conclude that the presence of the closed canopy in the RM site is not as important in determining decomposition rate as the intact soil, although the differences in moisture may be a factor in decomposition.

2. Litter Microarthropods

Methods

Microarthropods were extracted from litterbags using a modified Tullgren funnel apparatus (Mallow and Crossley 1984). Litterbags were left on the funnels for 3 to 4 days; the extracted microarthropods were preserved in 70% ETOH. Microarthropods were sorted under a stereomicroscope into the following categories: oribatid, prostigmatid, and mesostigmatid mites, Collembola, and others. Microarthropod abundances were determined as the mean number of animals/15.43gr litter. Since the abundance values were not normally distributed, the data were analyzed using a Generalized Linear Model (Proc Genmod SAS version 8e, 2000) (Crawley 1993). Standard errors in graphs are provided for comparison purposes, but aren’t statistically rigorous because the data do not conform with the assumptions of normality.

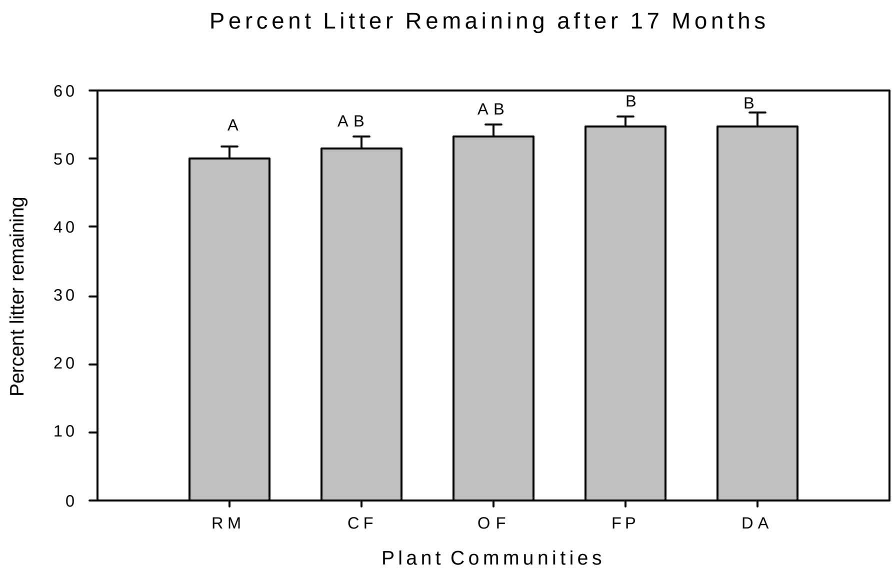


Fig. 7. Percent litter remaining in litterbags after 17 months in the field. Plant communities are RM=red maple, CF=closed fen, OF=open fen, FP=flood plain, and DA=disturbed alluvial bottomland forest. Each bar is the average of 37 to 48 litterbags. Bars with the same letter are not significantly different; error bars are ± 1 SE.

Results and Discussion

As expected, microarthropod numbers varied significantly among the three dates analyzed (Table 21, Fig. 8). Similar seasonal variations have been reported for upland hardwood forests in the southern Appalachians (Reynolds et al. 2003). We also found differences in litter microarthropod numbers by site for total microarthropods and all individual taxa counted except for prostigmatida, which were not abundant enough for statistical analysis. However, due to significant date*site interactions, the interpretation of significant site differences for mesostigmatida and collembola is unclear (Table 21).

In all sites, oribatid mites were by far the most common microarthropod (Fig. 8) and they were most abundant in the RM community, followed by CF. Abundances of oribatids (and total microarthropods) appear to be significantly lower in OF, FP, and DA. These findings could be related to the presence of a canopy in RM and CF, protecting litter-dwelling arthropods from extremes in temperature and from dessication when exposed to solar radiation. However, the low numbers of total microarthropods in DA and FP, compared to sites with more canopy (RM, CF, and OF), before leaves are present in March (Fig. 9), indicates that other factors are involved. We posit that soil disturbance, once again, plays a major role in a critical ecosystem factor – the abundance of litter microarthropods.

Table 21. Microarthropod responses to date and site. Data analyzed were average numbers of microarthropods per 15.43 grains of red maple litter from litterbags collected on each of three dates (March, May, and July of 2003).

Organism	Log-Likelihood	Terms	Chi-square	df	P
Total	487.56	Date	40.72	2	<0.0001
		Site	16.08	4	0.0029
		Date*Site	11.31	8	0.1850
Oribatida	400.99	Date	33.20	2	<.0001
		Site	14.76	4	0.0052
		Date*Site	10.57	8	0.2275
Mesostigmatida	157.29	Date	54.54	2	<0.0001
		Site	11.09	4	0.0256
		Date*Site	17.17	8	0.0284
Collembola	55.26	Date	9.40	2	0.0091
		Site	23.38	4	0.0001
		Date*Site	19.25	8	0.0136

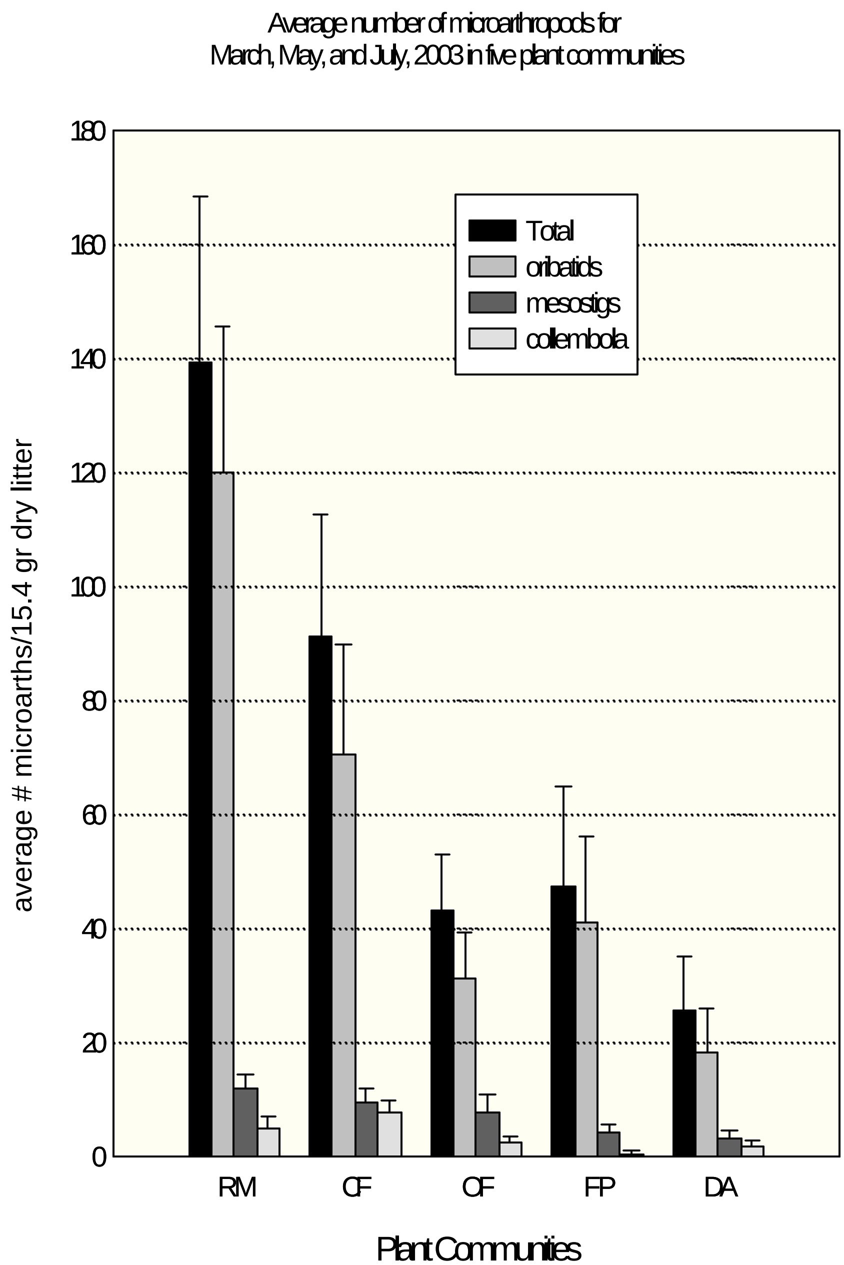


Fig. 8. Average number of microarthropods/15.43 gr dry red maple litter for all three collection dates, March, May and July, 2003. Plant communities are RM=red maple, CF=closed fen, OF=open fen, FP=flood plain, and DA=disturbed alluvial bottomland forest. Each bar is the average of 15 to 18 litterbags; error bars are ± 1 SE.

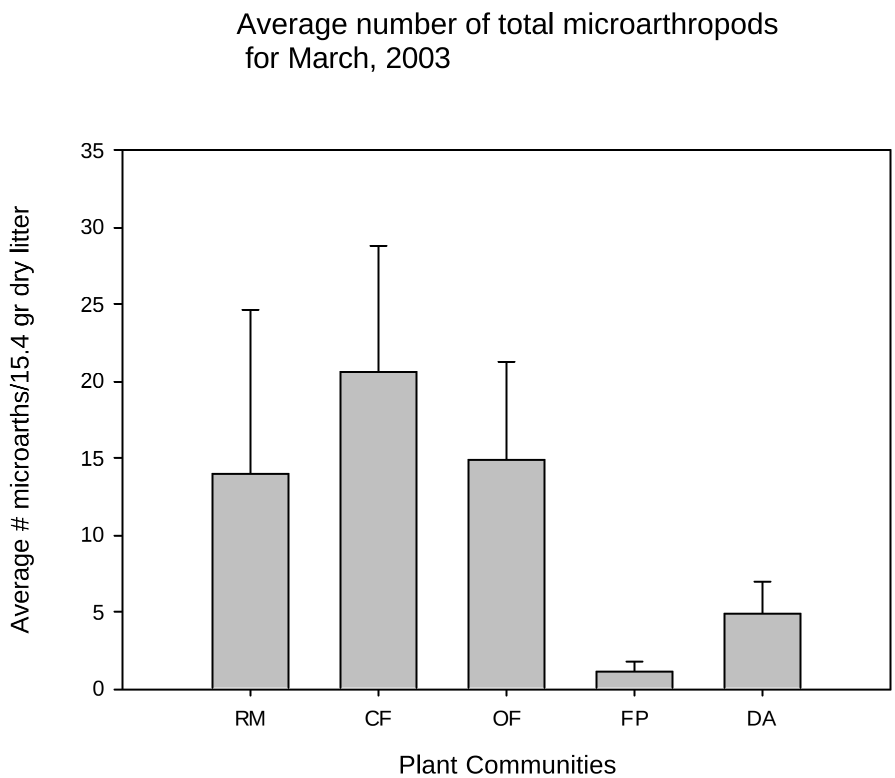


Fig. 9. Average number of total microarthropods/15.43 gr dry red maple litter for March, 2003. Plant communities are RM=red maple, CF=closed fen, OF=open fen, FP=flood plain, and DA=disturbed alluvial bottomland forest. Each bar is the average of 6 litterbags; error bars are ± 1 SE.

3. Soil Properties

Methods

Eight samples were collected from the top 2" of soil from each litterbag plot with a soil probe in July 2003. Those samples were then composited into one sample/plot, giving 6 samples per plant community. Percent organic carbon (OC) content was determined by the Walkley-Black method (Nelson and Sommers 1982); pH was measured on a 1:1 slurry of soil:distilled water using a Fisher Accumet pH meter and standard electrodes. Average values of pH and OC were calculated for each plant community and comparisons among the 5 sites were done using Tukey's Studentized Range (HSD) test, SAS version 8e (2000).

Results and Discussion

Average organic carbon varied from 11.79% to 2.8%, and was highest in soils from the open fen (11.79%), with OC decreasing in this order: closed fen (11.11%) > red maple forest (9.52%) > flood plain (8.53%) > disturbed alluvial forest (2.80%) (Fig. 10). The significantly lower OC for DA is probably the result of bulldozing the area for a fairway. Sites with the least disturbance, the fens and red maple forest, have the highest OC in the soil. Since soil organic matter is known to be strongly influenced by soil fauna (Coleman and Crossley 1996), these results appear to be correlated with the distribution of microarthropod abundances, especially for RM and OF (Fig. 8).

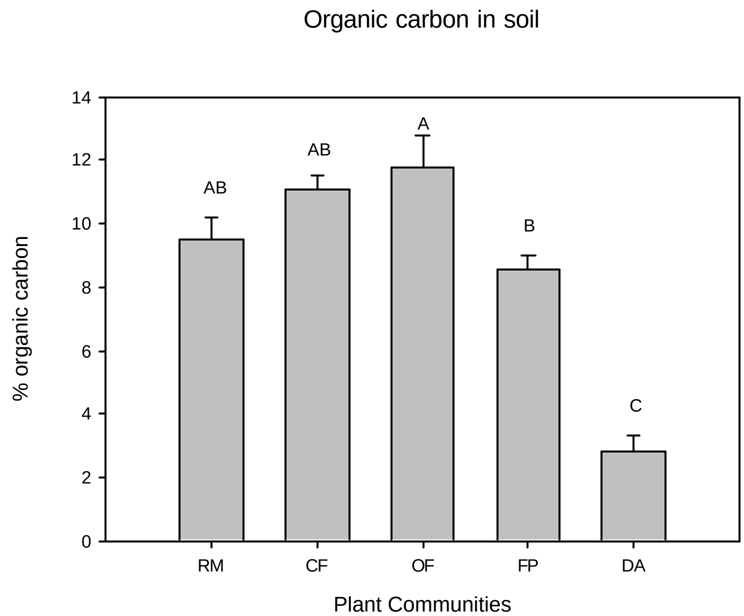


Fig. 10. Average percent organic carbon for soil from five plant communities: RM=red maple, CF=closed fen, OF=open fen, FP=flood plain, DA=disturbed alluvial bottomland forest. Each bar is the average of 48 soil samples. Bars with the same letter are not significantly different; error bars are ± 1 SE.

Average soil pH values ranged from 4.36 to 3.72, with the DA having the highest pH (4.36), followed by FP (4.2), OF (4.04), CF (3.98), and RM (3.72) (Fig. 11). pH is significantly lower for the red maple forest.

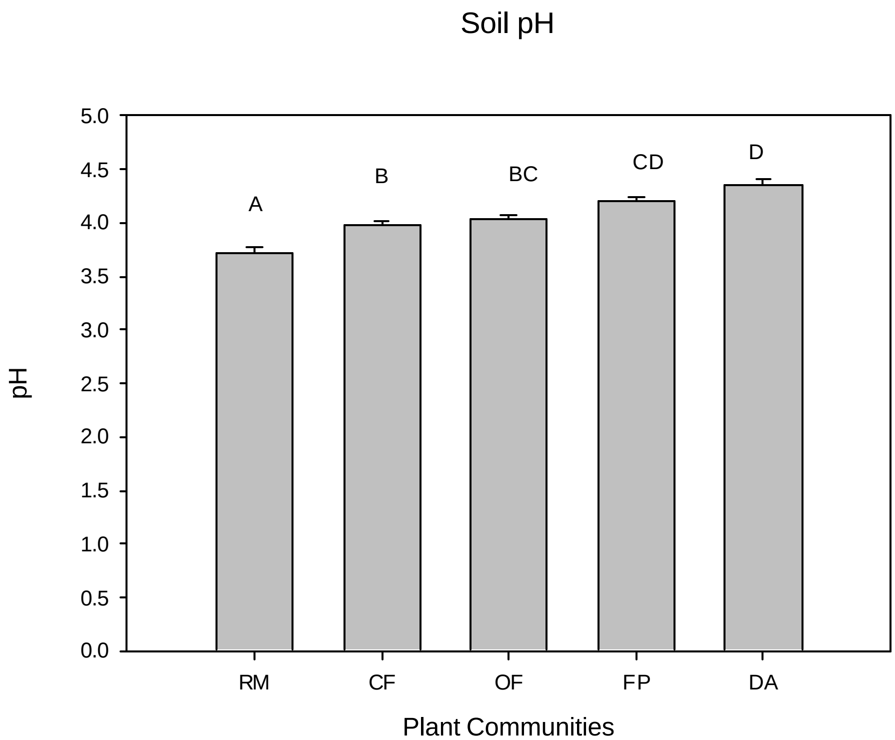


Fig. 11. Average pH for soil from five plant communities: RM=red maple, CF=closed fen, OF=open fen, FP=flood plain, and DA=disturbed alluvial bottomland forest. Each bar is the average of 48 soil samples. Bars with the same letter are not significantly different; error bars are ± 1 SE.

Summary of Decomposition and Soil Fauna

We found that the least disturbed plant communities, red maple in particular, have the quickest decomposition, the greatest amount of litter microarthropods, the most soil organic carbon, and the lowest soil pH. We conclude that soil characteristics, related to less disturbance, rather than the presence of a closed canopy, are probably the main influences on decomposition and litter microarthropods. Therefore, the most intact ecosystems appear to be functioning at the healthiest levels.

D. Amphibian Use of Tulula

Introduction

Amphibians are increasingly being used as indicator species in restoration projects for small freshwater wetlands (e.g., Pechmann et al. 2001) because they are often community dominants, are sensitive to site hydrology, and can be easily monitored to assess ecosystem function. Amphibians play key ecological roles in wetlands in the southern Appalachian Mountains, and are the dominant vertebrate group in standing water habitats at Tulula. Because a major goal of wetlands restoration is to restore ecosystem integrity (e.g., to create functional ecosystems where all major community elements are sustained at viable levels), the response of amphibians to site restoration is a useful indicator of ecosystem function.

Because of their strong reliance on seasonal wetlands for breeding, the reproductive success of many amphibian species is strongly influenced by hydroperiod (seasonal duration of ponds). The hydroperiod affects the likelihood of amphibian larvae reaching a minimum developmental stage to complete metamorphosis. It also influences the distribution and abundance of predators such as fish and aquatic insects that feed on amphibian eggs and larvae. Short hydroperiods during periods of drought can result in catastrophic mortality of larvae due to premature pond drying, but also reduce or eliminate aquatic predators. Long hydroperiods during wet years provide ample time for amphibian larvae to complete metamorphosis, but may result in heavy mortality from predators such as dragonfly larvae that prefer semi-permanent ponds.

At the initiation of the study in 1994, the site contained aquatic habitats that varied from highly ephemeral to permanent ponds. Most natural breeding sites were filled during golf course construction. During a detailed survey of the site during 1994-1995, we located 155 standing-water habitats that included 11 permanent ponds that were constructed as golf course obstacles. Permanent ponds contained predatory fish (bluegills, largemouth bass) and were not used as breeding sites by most resident amphibians. The remaining 144 sites were fish-free, seasonal habitats that were mostly small, shallow depressions. These included mud puddles, water-filled tire ruts, test wells for pond sites, sluggish ditches, and stream cut-offs associated with the channelization of Tulula Creek.

Monitoring of seasonal habitats during 1994-1995 indicated that most breeding sites were of very low quality because of altered site hydrology associated with stream channelization, ditching, and the filling of low-lying areas. All species of vernal pond-breeders suffered high larval mortality during 1994 and 1995 because most breeding sites dried prematurely before tadpoles or salamander larvae could complete their larval stages. Despite heavy rains in late winter and early spring, about 75% of the breeding sites dried prematurely in 1994 and 60-70% in 1995. These observations indicated a need to construct larger and deeper ponds to replace natural breeding sites that were destroyed during golf course construction.

Ten vernal ponds were constructed between October 1995 and January 1996 to replace natural breeding habitats. Depth and contour were manipulated to create seven temporary and three permanent fish-free ponds that provide suitable habitat for all pond-breeding amphibians at Tulula. At seven sites small standing water habitats existed prior to the construction of ponds. We selected 10 of the largest existing breeding sites as reference ponds to compare hydrological, physiochemical, and biotic characteristics. One reference pond was destroyed in 2001 in conjunction with reconstruction of the stream channel. Two others did not fill in 2001-2002 due to construction activity, but were functional in 2003 and 2004.

Thirteen new breeding sites were also created in the fall of 1999 when golf course ponds were either filled or partially filled to create shallow ponds. Most of these were stream-fed, and now exist as shallow, permanent sites that contain small fish. In others, fish were eliminated and the sites were converted into temporary ponds. Sections of the restored stream channel also were temporarily blocked with check dams to allow channel re-vegetation prior to restoring stream flow. Small pools formed in the deepest sections of these channel segments and were used as breeding sites by resident amphibians in 2001. Additional pools were formed in conjunction with stream and site restoration in 2001-2003. In February 2004 the site had over 60 breeding sites (Fig. 12).

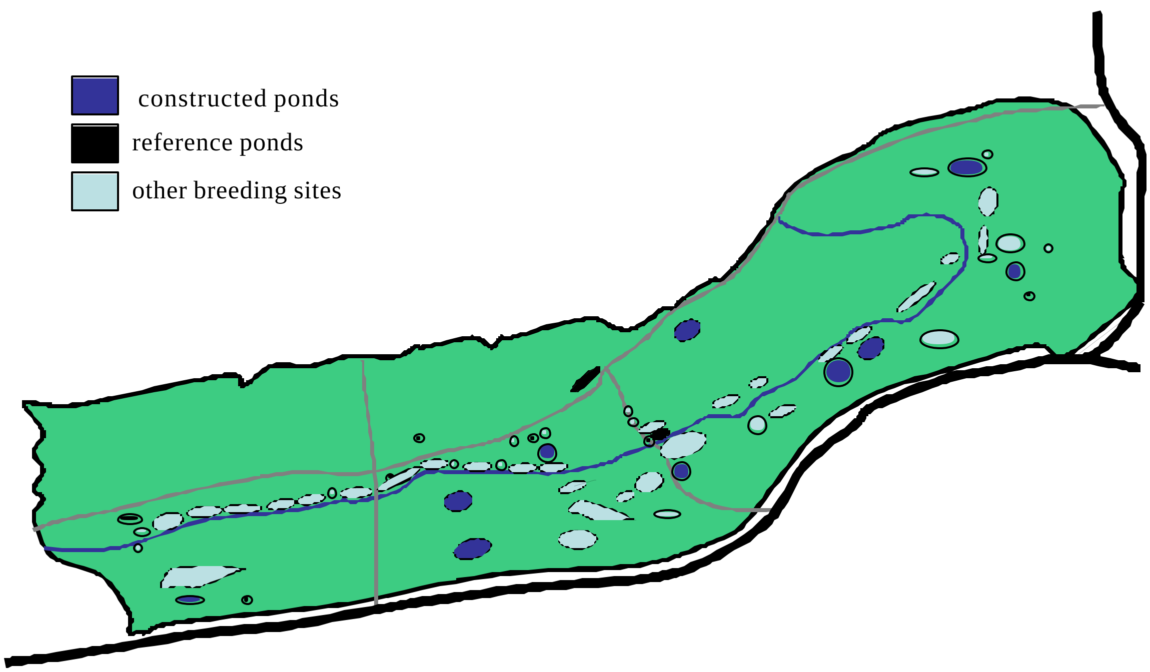


Fig. 12. Location of standing water habitats within the study site (spring 2004).

Methods

The 10 constructed and 10 reference ponds were sampled 3-19 times annually to obtained data on pond pH, temperature, conductivity, and oxygen saturation. Samples were taken during the day (900-1700 hrs) and all constructed and reference ponds were sampled haphazardly during the same day. Three subsamples of water were taken from each pond at approximately equidistant points along the center of the long axis and approximately 10 cm below the water's surface. Subsamples were pooled and readings were taken from the pooled sample. Samples were placed on ice during warm weather and dissolved oxygen was measured in the field < 3 hours after samples were collected using Corning Check-mate meters. Conductivity and pH were measured using Corning Check-mate and Corning 430 bench meters, respectively. We used the yearly mean for all seasonal samples in statistical comparisons of reference and constructed ponds.

Results

Reference ponds were smaller and shallower than constructed ponds, which could influence physiochemical characteristics. At full capacity, surface areas of reference ponds averaged 888 ft^2 (range = 145-2367 ft^2) versus 5165 ft^2 (range = 2421-9931 ft^2) for constructed ponds. Respective values for maximum depths were 13.4 inches (range = 5.1-23.6 inches) and 24.4 inches (range = 15-34 inches). Comparisons of physiochemical characteristics of constructed and reference ponds from 1996-2004 are in Fig. 13.

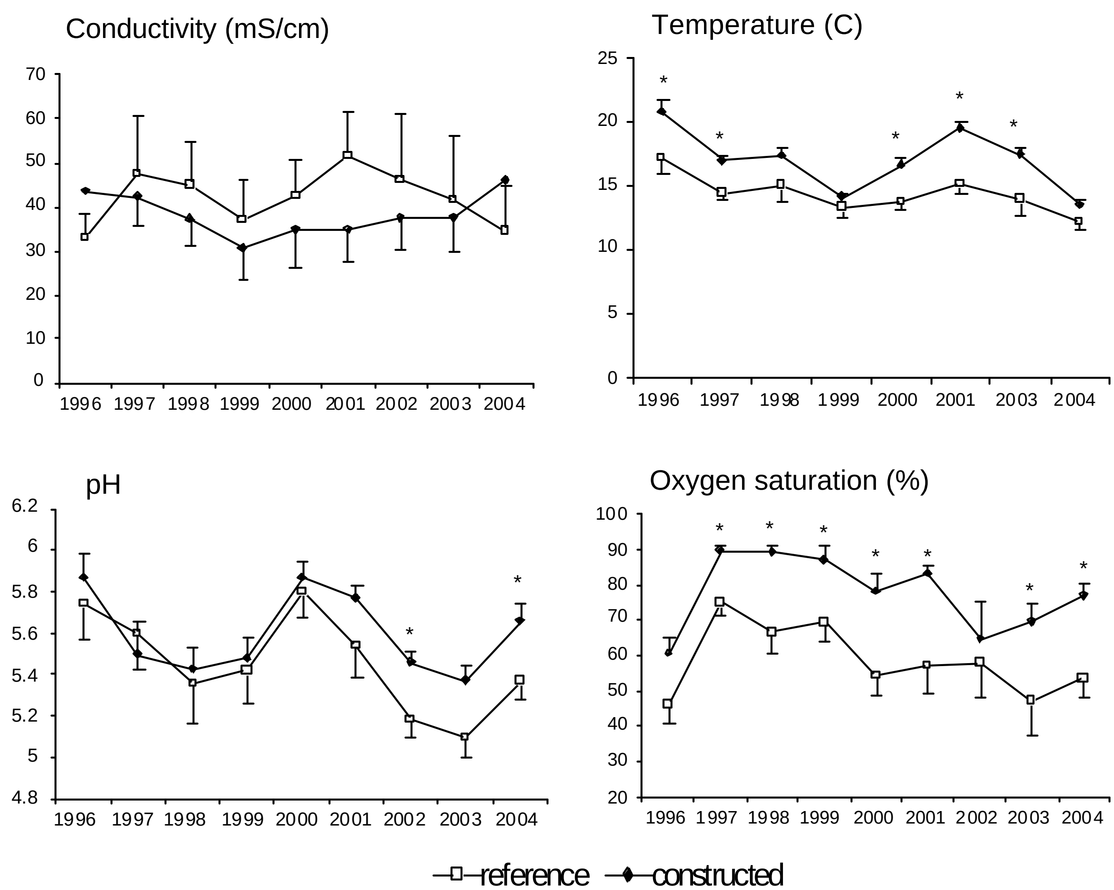


Fig. 13. Physiochemical characteristics of reference and constructed ponds. Symbols are annual means based on 3-19 seasonal samples per year. Vertical bars are 1 SE. Asterisks indicate means that differed significantly within years.

Respective grand means (+ 1 SE) based on annual averages for reference versus constructed ponds were 5.46 (0.08) versus 5.60 (0.05) for pH, 14.4°C (0.53) versus 17.1°C (0.86) for temperature, 42.1 (2.09) versus 38.3 (1.60) dS/cm for conductivity, and 58.8 (3.3) versus 77.8 (3.6) for percent O_2 saturation. T-tests (alpha = 0.05) indicate that means for pH differed only in 2002 and 2004, while conductivity did not differ significantly for any year (conductivity: $P > 0.19$). However, constructed ponds were significantly warmer in five of seven years and had significantly higher oxygen saturation levels in all but two years.

2. Use of constructed and reference ponds by amphibians.

Methods

All constructed ponds filled with water before amphibians began breeding in February 1996. We monitored all constructed and reference ponds annually to determine patterns of use by resident species. We visited ponds every 1 to 3 weeks between January-August and searched for amplexed adults, eggs, or larvae. Larvae were collected when conducting open-bottom sampling to estimate survival (see below) and when ponds were dip-netted periodically during the spring and summer to sample resident amphibians.

Results

Resident amphibians rapidly colonized constructed ponds that first filled in 1996 (Fig. 14). Eight species of amphibians bred in the constructed ponds within 1 year of construction and 10 species have used the ponds through 2004. These are the wood frog, green frog, bullfrog, gray treefrog, spring peeper, American toad, spotted salamander, red salamander, three-lined salamander, and the red-spotted newt (Appendix F). The only species unique to constructed ponds was the bullfrog, which prefers permanent or semipermanent habitats. Reference ponds were also used by 10 species of amphibians and only one, the two-lined salamander, was unique to reference ponds (breeding in 1 of 10 reference ponds).

Overall, constructed ponds contained a significantly greater number of breeding species (mean + 1 SE = 4.21 + 0.24 species) than reference ponds (2.74 + 0.16 species) during the 8-year period (paired t-test; $P = 0.0002$). For individual years, the mean number of species per pond was significantly higher in constructed ponds for five of eight years and approached significance ($P < 0.10$) for two other years (Fig. 14). Regression analysis indicates that the mean number of species using ponds annually did not increase between 1996-2003 (P values for reference and constructed ponds = 0.92 and 0.19, respectively). The latter suggests that constructed ponds quickly reached saturation levels within one year of construction. A more detailed analysis of pond colonization and community turnover is in Petranka (2000a).

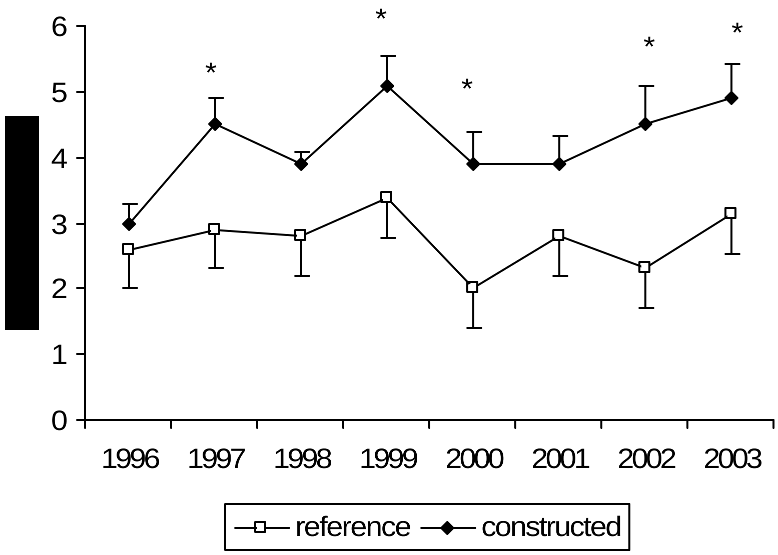


Fig. 14. Mean number of species that bred in reference and constructed ponds. Symbols are means and bars are + 1 SE. Years with asterisks are significantly different.

3. Response of focal species to constructed ponds.

Methods

We selected the spotted salamander (*Ambystoma maculatum*) and wood frog (*Rana sylvatica*) as focal species for monitoring ecosystem function and restoration success. Both species are widely distributed across the site and are largely restricted to temporary ponds that predominated prior to golf course construction. These species lay large egg masses that can be accurately counted, and that serve as an index of the size of the female breeding population.

To obtain estimates of the overall response of the focal species to restoration efforts, we conducted a complete count of egg masses on the eastern half of the site beginning in 1995. This census included the 10 constructed ponds, the reference ponds, and all other breeding sites in the eastern sector.

To estimate relative changes in embryonic and larval survival across years, we estimated the total population size of hatchlings and larvae nearing metamorphosis in each pond using open-bottomed samplers. Populations were sampled using 30 gallon galvanized trashcans with bottoms that were removed with a blowtorch (approximate area of can bottom = 1.2 ft^2). When sampling, the can was pushed into the pond substrate to trap larvae. Repeated sweeps of the can were made with aquarium nets until no larvae were captured for five consecutive sweeps.

Ponds were sampled by walking a zig-zag transect across the entire area of the pond and taking samples at approximately equidistant points along the transect. The number of samples per pond increased with pond size and varied from 15-80. If ponds were not at full capacity, then pond surface area was estimated at the time of sampling based on 3-5 measurements of length and width using a meter tape. The total population size of hatchlings or larvae nearing metamorphosis was estimated using data on the mean number of larvae per sample, the surface area of the sampler, and the surface area of the pond.

We obtained an initial sample of hatchlings within 1-3 weeks after > 95% of the egg masses were estimated to have hatched in a pond. We intensively dip-netted ponds as larvae approached metamorphosis, and obtained a final sample immediately after the first metamorphosing larva was observed in each pond. Criteria used to recognize metamorphosing larvae were the emergence of both front legs for wood frog tadpoles and the partial or complete reabsorption of gills and dorsal fins for spotted salamander larvae. We used this estimate as a relative measure of the number of juveniles that were recruited into the terrestrial population each year.

Changes in adult population size are the most meaningful measure of the response of amphibians to site restoration efforts. However, a significant time lag in population responses occurs because of the prolonged juvenile stage. That is, juveniles that metamorphose and leave ponds may not return for 2-4 years as breeding adults. We used total egg mass censuses of the eastern half of the site to measure the effects of pond construction and site restoration on breeding populations.

Results

The responses of breeding populations of wood frogs and spotted salamanders to pond construction are shown in Fig. 15. These data exclude two constructed ponds (7X; 10X) that occurred on the western end of the site and three small reference ponds that were either destroyed (2C) or were nonfunctional in 2002 (3C; 4C) and 2003 (4C only) due to construction activities. During 1996 (first year after pond construction and filling), 71% of the resident wood frogs and 59% of spotted salamanders bred in the constructed ponds. A corresponding decline in breeding effort occurred in the remaining small depressions, suggesting that many adults abandoned historical breeding sites in favor of newly constructed ponds.

The percentage of adult wood frogs that bred in constructed ponds between 1996 and 1999 increased slightly. However, adults decreased use of constructed ponds after 1999 and shifted to other sites. This reflects a progressive increase in the number of ponds on site in association with stream and final site reconstruction. In contrast, use of constructed ponds by spotted salamanders was similar across years, perhaps because adults favor larger, deeper ponds for breeding. In 2004, approximately 48% of wood frogs and 44% of spotted salamanders bred in the constructed ponds, while reference ponds provided breeding habitat for < 8% of the population.

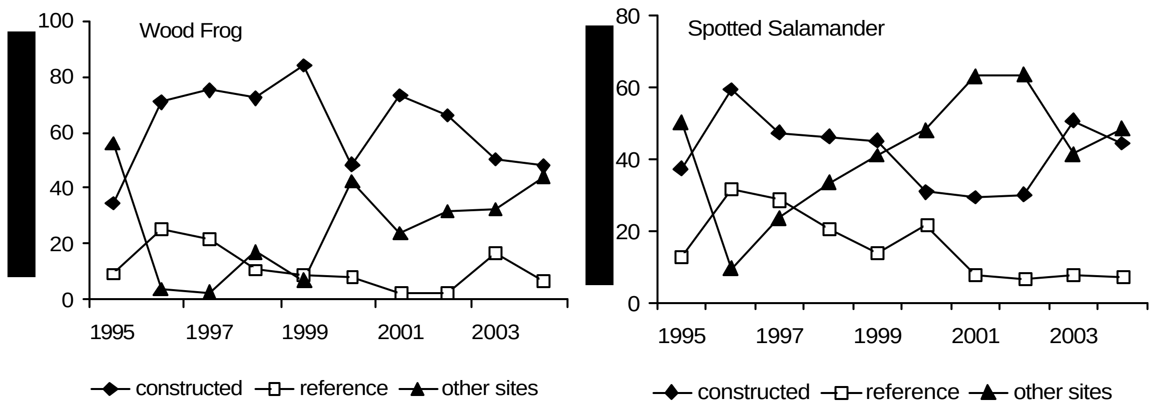


Fig. 15. Response of female wood frog and spotted salamanders to pond construction. Symbols are the number of egg masses laid on the eastern half of the site in constructed ponds, reference ponds, and all remaining breeding sites. Numbers are expressed as a percentage of all masses laid in the eastern half of the site. 'Other" includes all sites other than reference and constructed ponds, including sites that were created during stream channel restoration. Data for 1995 'constructed' are masses laid in preexisting sites where ponds were constructed.

Fig. 16 shows annual changes in the percentage of ponds that successfully produced juveniles (upper graphs) and total yearly output of juveniles from constructed and reference ponds (lower graphs). The percentage of ponds that successfully produced juveniles has declined annual from 60-100% in 1996 to < 30% in 2003. The estimated output of terrestrial juveniles from constructed ponds was exceptionally high during 1996 (N = 253,696 wood frogs; 30,831 spotted salamanders), but progressively declined in later years (e.g., N = 5,819 and 753 in 2003, respectively). A similar trend occurred in reference ponds. These trends parallel a general decline in the percentage of ponds that have successfully produced juveniles each year. Nonetheless, a small percentage of ponds on site have successfully produced juveniles annually, and viable populations of both species occur on site (see below).

Comparisons of the number of hatchlings and number of larvae surviving to the initiation of metamorphosis (see Petranka 2003b for details) indicate that the decline in juvenile output was primarily due to increased larval mortality rather than increased embryonic mortality. Embryonic survival varied among years, but there was no evidence of catastrophic mortality for any year. In contrast, overall juvenile production per egg mass declined markedly during the study period for both species and both sets of ponds. The reduction in juvenile production is attributable to at least three factors: (1) premature pond drying and/or the failure of ponds to fill seasonally, (2) outbreaks of a pathogen that caused larval die-offs, and (3) the accumulation of predators in constructed ponds after 1996.

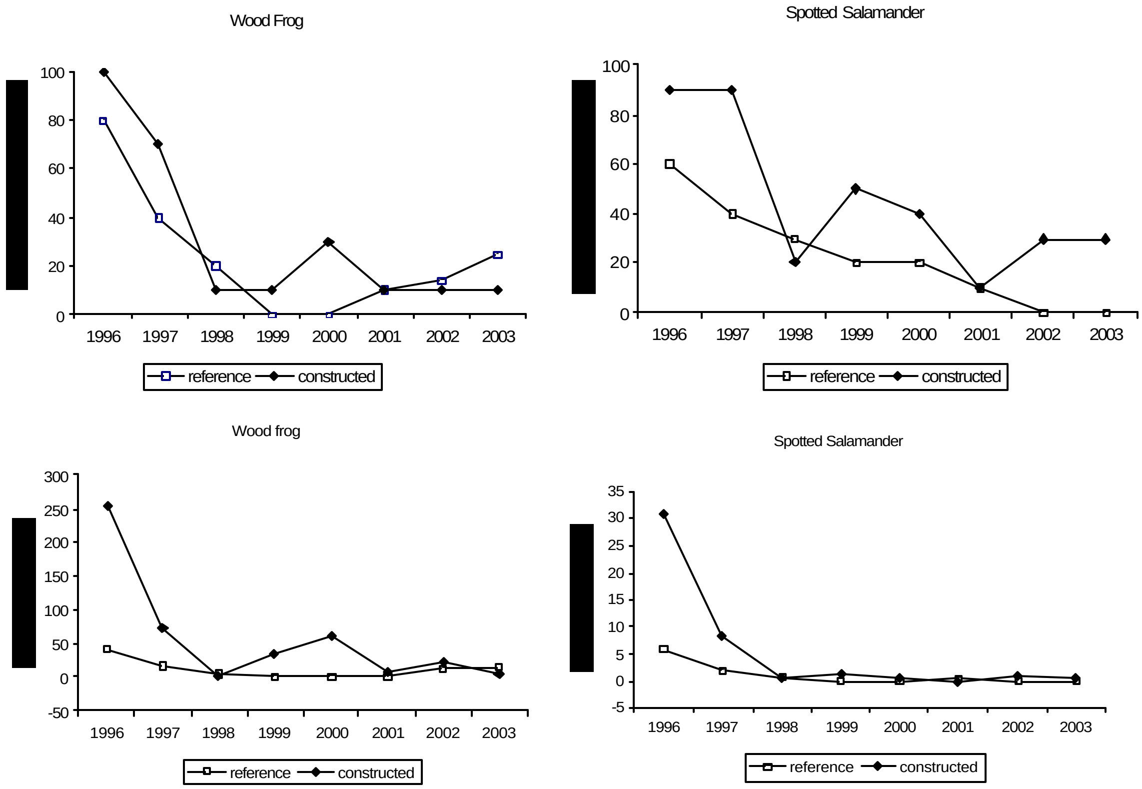


Fig. 16. Estimates of the percentage of ponds that produced juveniles, and total juvenile recruitment from 10 constructed and 10 reference ponds during 1996-2003. Symbols for upper panels are the percentage of ponds that produced juveniles annually, whereas those in the lower panels are the estimated number of larvae surviving to the initiation of metamorphosis (in thousands).

Fig. 17 shows the percentage of ponds that either did not fill or that filled and dried prematurely between 1996-2003. Constructed ponds filled annually and usually held water sufficiently long to allow metamorphosis of both species. An exception is 2001 when 20% of ponds dried prematurely, causing catastrophic mortality.

The more shallow reference ponds tended to progressively deteriorate with respect to hydroperiod between 1996-2002. During 2002, 43% and 100% of the reference ponds either did not fill or dried prematurely for *Rana* and *Ambystoma*, respectively. This pattern may in part reflect a regional drought that occurred from the summer 1998 to fall 2002. The proportion of reference ponds that dried prematurely decreased after 2001-2002 as the drought ended and rainfall increased to average or above average levels.

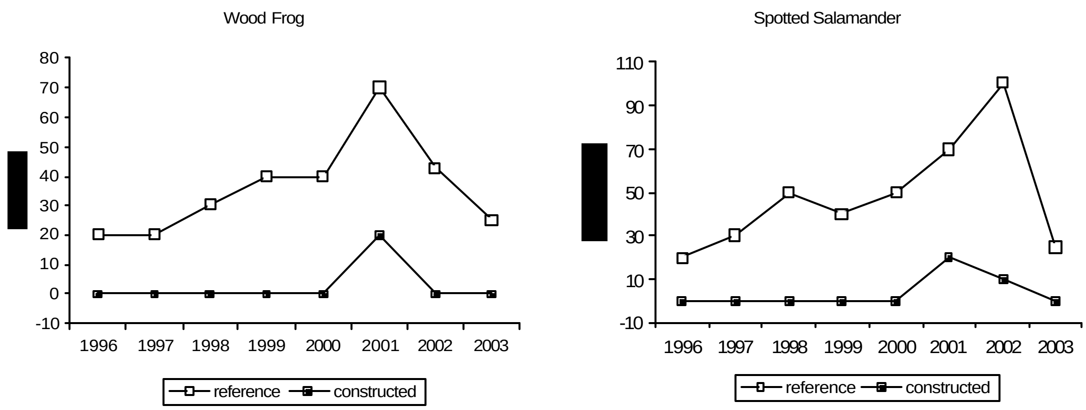


Fig. 17. Annual variation in the percentage of constructed and reference ponds that either did not fill or that dried before larvae could initiate metamorphosis.

Disease is a second factor that contributed strongly to the decrease in juvenile output between 1996-2003. Outbreaks of a disease that caused catastrophic larval mortality were first observed in 1997. Moribund specimens were sent to the National Wildlife Health Center in Madison, Wisconsin, and detailed histological and molecular studies revealed that the pathogen is an iridovirus (*Ranavirus*).

Larvae of both the wood frog and spotted salamander are susceptible to *Ranavirus* infections. Infected larvae tend to become lethargic, often float at or near the water surface, and develop characteristic bloody, hemorrhagic patches on the body and fins. Infected larvae are first noticed seasonally during the mid- to latter half of the larval stage. Catastrophic mortality typically occurs within 1-2 weeks after the first infected individuals are detected. Typically, outbreaks result in 100% mortality of larvae in a pond.

The extent to which the disease has impacted local populations in reference and constructed ponds at Tulula is shown in Fig. 18. Diseased animals and die-offs were not observed prior to 1997, at which time two die-offs occurred in two ponds. The disease rapidly spread to other ponds on site and has been a major source of larval mortality since 1998. The smaller percentage of reference ponds with die-offs between 1998-2002 reflects the fact that many reference ponds dried prematurely (e.g., prior to the time when the disease normally develops

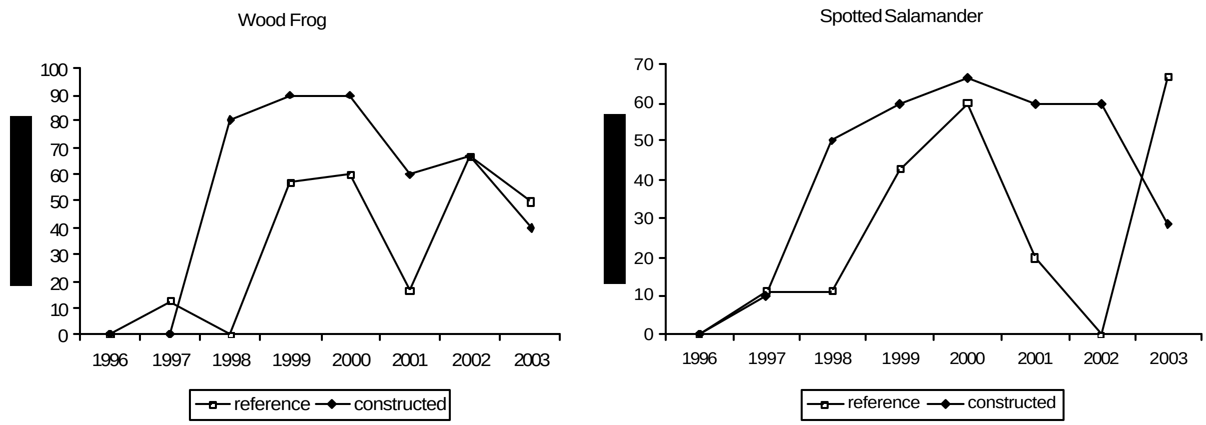


Fig. 18. Changes in the percentage of reference and constructed ponds in which catastrophic die-offs of larvae occurred from *Ranavirus* infections.

Egg and larval predation was the third significant source of premetamorphic mortality that contributed to the decline in juvenile output between 1996-2003. In particular, egg predation by green frog tadpoles on wood frogs (Petranka and Kennedy 1999), and wood frog tadpoles on spotted salamanders (Petranka et al. 1998) were significant sources of mortality in certain ponds. Odonates and other predatory aquatic insects accumulated in constructed ponds after 1996 and presumably contributed to higher larval mortality.

Despite impacts from drought, disease, and predators, populations of both species have not suffered severe crashes and remain at viable levels (Fig. 19). The size of the wood frog population declined from 1995-1998, increased dramatically (366%) through 2000, and declined thereafter. The population has remained relatively stable since 2002. Female wood frogs require 3-4 years to reach sexual maturity after metamorphosing (Bervin 1982). Thus, the marked increase in population size in 1999 corresponds to when the large output of juveniles in 1996 first returned to breed as adults. The decline since 2000 presumably reflects the impact of *Ranavirus* and premature pond drying on the adult population.

The population of spotted salamanders has not changed as markedly. The size of the breeding population slowly increased from 1995(N = 1,265 egg masses) to 2004 (N = 1,831 masses). Females of this species may require 3-5 years to reach sexual maturity (Petranka 1998), so the gradual increase in breeding population size may reflect recruitment from the relatively large output of juveniles in 1996 and 1997. The decline in 2002 may reflect the impact of *Ranavirus* outbreaks that began in 1997-1998. However, in 2004 the population reached the highest level (1,831 masses), indicating that recruitment has been sufficient to gradually increase population size.

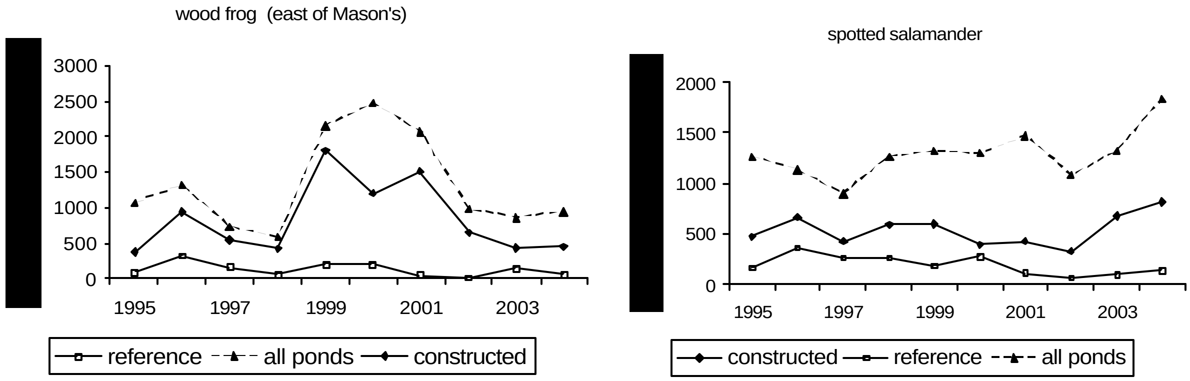


Fig. 19. Changes in adult breeding population size on the eastern sector based on annual egg mass counts in all breeding sites.

4. Altered site hydrology and emerging concerns. The completion of reconstruction activities, above average precipitation in 2003-2004, and invasions of the site by beavers have increased the number of habitats with fish. Damming of Tulula Creek by beavers caused spillover into most of the nearby wetlands that parallel the stream on the west end of the site (Fig. 12). Almost all of these sites now contain fish and provide little habitat for seasonal pond breeders. Although reference ponds are too ephemeral to support fish, fish have invaded many of the constructed ponds since 2002 (Fig. 20). Amphibians that use fish-free habitats have responded by not ovipositing in ponds with fish; however, it is uncertain whether adults that avoid ponds with fish are successfully breeding in other habitats on site.

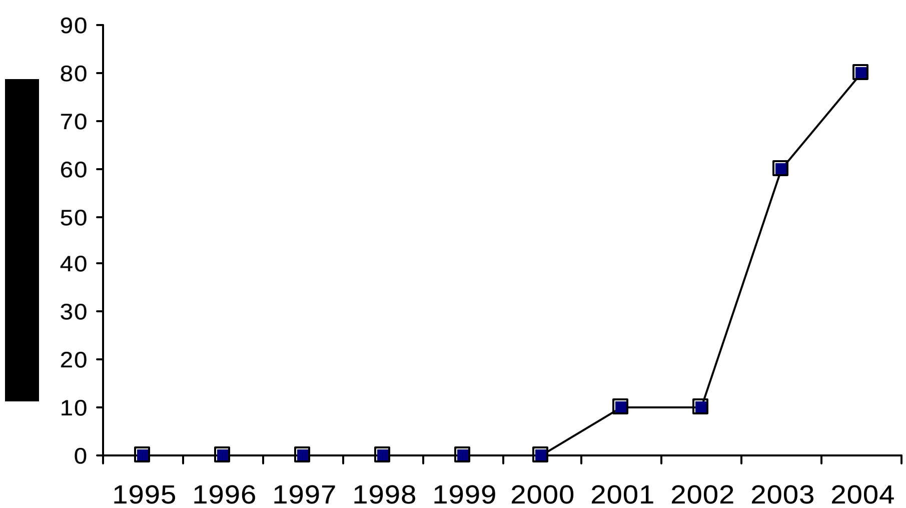


Fig. 20. Yearly changes in the percentage of the ten constructed ponds that contained fish.

Summary

Data collected from 1996-2004 indicate that constructed ponds are of higher quality than reference ponds based on physiochemical characteristics, seasonal hydroperiod, and use by resident amphibians. The constructed ponds tended to be warmer and have higher oxygen levels. Since larval growth is directly proportional to temperature, and high oxygen levels reduce physiological stress, physiochemical conditions are judged to be superior to those of reference ponds. Amphibians rapidly colonized the constructed ponds, and the number of species that utilize these as breeding sites averaged about 50% higher than that of reference ponds.

Reference ponds progressively deteriorated between 1996 and 2002 with respect to seasonal hydroperiod. In 2002 the majority either did not fill or dried prematurely, resulting in catastrophic mortality of pond populations. In contrast, the hydroperiod of most constructed ponds appears to be adequate for most vernal pond breeders. Seven of 10 ponds normally undergo seasonal drying in late summer or fall when larvae have metamorphosed. However, fish have colonized many since 2002 in association with above normal rainfall, beaver activity, and completion of the final phase of reconstruction.

Outbreaks of *Ranavirus* have dramatically reduced the output of juveniles from both constructed and reference ponds. Similar outbreaks of this disease have been reported in several areas of the United States (Daszak et al. 1999) and have resulted in catastrophic die-offs of larvae. Amphibians often exhibit boom-and-bust recruitment patterns in which juvenile recruitment may be near zero in some years and high in others (e.g., Gill 1978, Semlitsch et al. 1996). Local populations are buffered from these effects since the adults may live many years and metapopulation dynamics allow for some recruitment annually. Thus, years with complete reproductive failure in local ponds may not necessarily translate to long-term declines of local populations. We have documented high rates of reproductive failure in most ponds in most years. However, annual recruitment from a small subset of ponds annually appears to be sufficient to maintain viable adult populations of wood frogs and spotted salamanders.

Scientists currently know very little about the epidemiology of amphibian *Ranavirus*. For example, it is unknown how the virus is spread between ponds, whether a subset of larvae are resistant to the virus, or whether the infections subside after several years of outbreaks. Preliminary studies that we have conducted suggest that humans and other vertebrates such as raccoons and birds may play a role in spreading the disease via movement of contaminated mud or water between local ponds. One scenario for the Tulula populations is that the severity of die-offs will decline with time as local populations evolve immunity or as the virus undergoes normal erratic patterns of outbreak. A second is that the virus will consistently produce annual die-offs in most ponds that do not dry prematurely. If the proportion of ponds that suffer die-offs increases significantly in the future, then the latter could result in resident amphibian species undergoing population bottlenecks or even local extinctions.

The invasion of beavers (*Castor canadensis*) and the completion of stream restoration are influencing site hydrology and the dynamics of amphibian populations at Tulula. Beaver invaded the site shortly before stream channel construction began and were eliminated through trapping. They have since reinvaded and have significantly altered the landscape. Fish have become far more abundant on site since 2002 and have invaded most of the constructed ponds. In general, habitat quality for amphibians that use seasonal wetlands has declined. Monitoring of focal species in future years will document how amphibians respond to altered hydrology from stream restoration and beaver activity. It will also help resolve the extent to which *Ranavirus* infections ultimately impact breeding populations of amphibians.

D. Bird Use of Tulula

Birds are used as a common indicator for assessing changes in habitat attributes that are associated with many types of restoration projects (Morrison 1986). Since 1994, we have conducted breeding bird surveys and measured habitat characteristics of the Tulula floodplain (Rossell et al. 1999, Moorhead et al. 2001). Restoration of Tulula Creek was completed during the summer of 2002. Here we report results of breeding bird surveys and habitat analyses conducted during 2004. These results are the first year of data evaluating the response of bird populations to post-restoration habitat changes at Tulula.

1. Bird Surveys

Methods

Breeding bird surveys were conducted from 17 May to 29 May 2004, at 65, 25-m radius plots located across Tulula floodplain (Fig. 21). Thirty-two plots were separated by at least 100 m. An additional 33 plots were separated by at least 50 m and surveyed because habitat data have been collected at these plots since 1994 (see Bird-Habitat Relations below). Surveys were conducted from sunrise until 1000 hrs. After a 1-min quiet time, all birds heard or seen within 25 m of the plot center were recorded for 3 min. Birds that flushed within 25 m of the plot center during the approach also were recorded. Plots were sampled three times during the survey period. Bird richness was defined as the total number of species, and relative bird abundance was defined as the total number of individuals of a species.

Results and Discussion

Results of breeding bird surveys are presented in Table 22. In 2004, species richness declined 15% from 2002 levels, with 33 species recorded. American Woodcock, Common Grackle, and Eastern Wood-pewee were new species recorded during surveys (See Appendix C for complete list of birds and scientific names). Common Grackle and Eastern Wood-pewee are common in the mountains of North Carolina (Hamel 1992), and both species were likely breeding on site. American Woodcock are considered rare in the southern Appalachians, although they have no designated conservation status (Hamel 1992). The American Woodcock is associated with moist woodland thickets and bottomland forests that have an abundance of dead leaves on the ground (Hamel 1992). American Woodcock have been observed in past years using the Tulula floodplain for singing grounds; this species likely breeds in low numbers throughout the site.

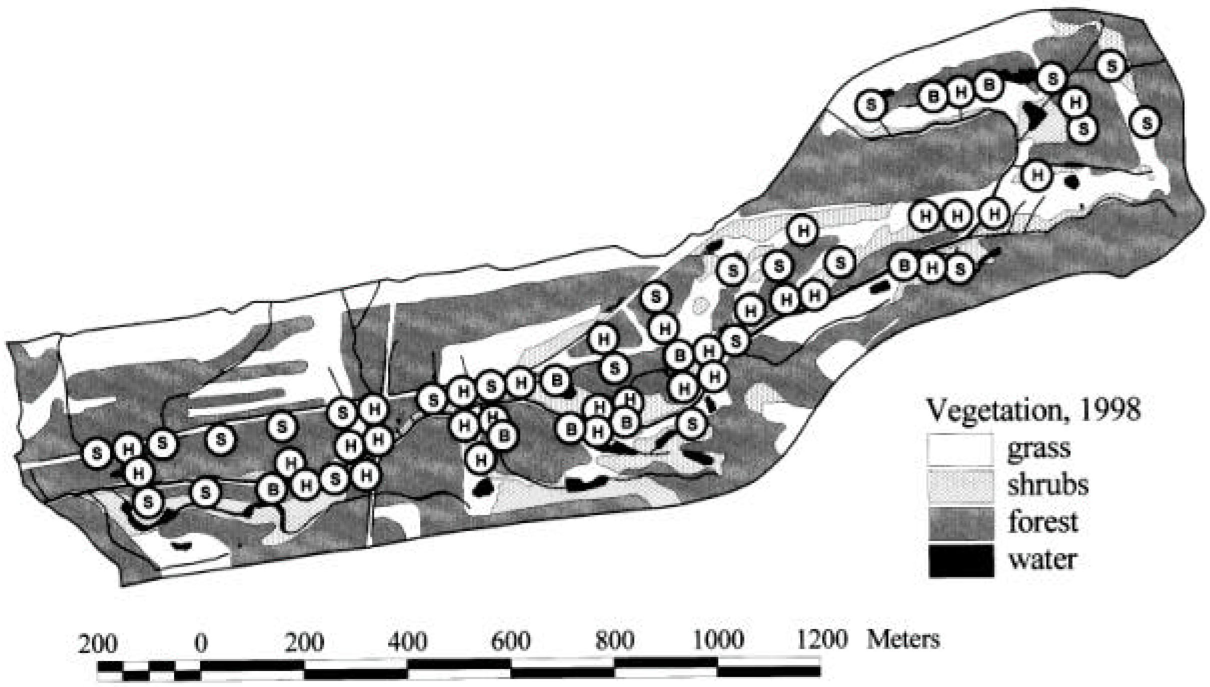


Fig. 21. Location of bird survey and habitat plots. S = survey plots, H = habitat plots, and B = survey and habitat plots.

Relative bird abundance in 2004 decreased 52% from 2002 levels, with a 166 total observations (Table 22). Song Sparrow and Rufous-sided Towhee continued to be the most abundant species on site, however, their numbers decreased by almost 50% from 2002 levels. Red-winged Blackbird also continued to be one of the most abundant species on site, but its numbers held steady relative to 2002 levels. Many species of conservation concern declined substantially in 2004 (Hamel 1992). The most notable declines included the Golden-winged Warbler, Hooded Warbler, and Yellow-breasted Chat. Golden-winged Warblers and Yellow-breasted Chats have declined steadily since 1998. Other species that declined in 2004 included Red-eyed Vireo and White-eyed Vireo. Brown-headed Cowbirds, which were breeding at Tulula in 2002, were conspicuously absent in 2004.

The declines in species richness and relative bird abundance are likely associated with the large proportion of the floodplain that was inundated with standing water. Beaver have colonized the western end of Tulula Creek, constructing a series of dams that flooded much of the interior of the site. The site was so wet during the spring of 2004 that chest waders had to be worn to conduct surveys. Species associated with standing water, such as Red-winged Blackbirds and Wood Ducks, have generally increased in abundance, while species associated with early-successional habitats, including many of the Neotropical migrants of conservation concern, have generally decreased in abundance.

The Golden-winged Warbler is the species of highest conservation concern breeding at Tulula. This species is federally listed as a species of special concern (LeGrand and Hall 2004). Since 1994, the Golden-winged Warbler has decreased 94% (31 to 2 birds) in breeding bird surveys at Tulula. Golden-winged Warblers require a variety of seral stages for breeding, including patches of herbaceous cover, shrub thickets, and a forested edge (Klaus and Buehler 2000, Rossell 2001, Rossell et. al. 2002). As a result of stream construction and backfilling the old stream channel during the spring of 2002, most of the herb and shrub layers were eliminated from the interior of Tulula. This area encompassed a substantial portion of many Golden-winged Warbler territories (Rossell et al. 2002). In 2004, additional habitat was lost due to the flooding of the site by beaver.

General observations of Golden-winged Warblers at Tulula indicated that 6-8 territories were established in 2004. The majority of territories were located along the periphery of the floodplain where conditions were drier and where there was a large shrub component. Areas with large amounts of standing water were generally not inhabited by Golden-winged Warblers. Interestingly however, all Golden-winged Warbler territories established in 2004 contained some standing water.

Table 22. Relative abundance and migratory status of birds recorded during breeding bird surveys in 65, 25-m radius (0.2 ha) plots during 1994, 1998, 2000, 2002, and 2004.

Species		1994 Number	1998 Number	2000 Number	2002 Number	2004 Number	Migratory Status*
Acadian Flycatcher		2	14	3	1	5	N
American Goldfinch		19	13	7	5	2	Y
American Robin		0	1	0	12	1	D
American Woodcock		0	0	0	0	1	D
Belted Kingfisher		0	1	0	0	0	Y
Blue-gray Gnatcatcher	11	13	10	9	11	N	
Blue-headed Vireo		0	0	0	1	0	N
Brown-headed Cowbird		0	0	0	2	0	D
Brown Thrasher		1	0	0	4	1	D
Black-and-White Warbler		1	3	1	0	3	N
Blue Jay		0	2	0	0	0	Y
Carolina Chickadee		15	4	7	10	8	Y
Carolina Wren		3	6	3	2	7	Y
Common Yellowthroat	7	1	0	2	5	N	
Chestnut-sided Warbler		23	2	7	14	3	N
Cedar Waxwing		9	10	4	9	0	D
Common Grackle		0	0	0	0	1	Y
Downy Woodpecker		6	1	2	3	2	Y
Eastern Phoebe		0	0	0	1	0	D
Eastern Wood-Pewee		0	0	0	0	1	N

Golden-winged Warbler		31	21	8	6	2	N
Gray Catbird		4	0	0	0	0	Y
Hooded Warbler		11	21	6	12	4	N
Indigo Bunting	83	55	15	17	13	N	
Kentucky Warbler		17	9	9	2	9	N
Mourning Dove		0	2	0	1	0	Y
Northern Bobwhite Quail		0	0	2	7	1	Y
Northern Cardinal		8	3	4	12	5	Y
Northern Flicker		1	0	0	1	0	Y
Northern Parula		17	24	10	26	11	N
Northern Rough-winged Swallow		0	2	0	4	0	N
Ovenbird		2	6	2	5	0	N
Pileated Woodpecker		0	2	1	2	1	Y
Red-eyed Vireo		21	28	28	25	10	N
Ruby-throated Hummingbird		6	5	6	7	3	N
Rufous-sided Towhee		22	24	14	26	15	Y
Red-winged Blackbird	0	0	0	13	12	D	
Scarlet Tanager		0	1	1	0	0	N
Song Sparrow		4	11	11	31	16	Y
Swainson’s Warbler		1	4	0	0	0	N
Tufted Titmouse		3	5	8	11	5	Y
White-breasted Nuthatch		1	0	1	1	1	Y
White-eyed Vireo		22	26	29	20	3	N
Wood Duck		0	0	0	1	2	D
Wood Thrush		0	1	0	3	1	N
Yellow-breasted Chat		18	23	12	7	1	N
Yellow-throated Vireo	4	1	3	3	0	N	
Yellow-throated Warbler		3	4	1	3	0	N
Yellow Warbler		0	1	0	0	0	N
Total Species		31	36	29	39	33	
Total Individuals		378	350	215	321	166	

*Note: Migratory status from Hamel (1992).
N = Neotropical migrant, D = Short-distance migrant, Y = Year-round resident.

2. Bird-Habitat Relations

Methods

Habitat data were collected in 41, 25-m radius (0.2 ha) permanent plots from 7 June to 28 June 2004. Bird-habitat plots were selected in 1994 based on the criterion that they had at least one bird species recorded in two out of three surveys. Within each plot, herbaceous cover, shrub thickness, and canopy cover were estimated at 16 regularly spaced points along two perpendicular transects. Understory (2.5-10 cm dbh) and overstory (> 10 cm dbh) tree densities were also estimated in each plot using the closest individual method (Bonham 1989). Herbaceous cover was estimated for vegetation < 0.5 m in height using a 0.25-m^2 quadrat. Shrub thickness was estimated for vegetation 0.5-2 m tall using a shrub profile board (Hays et al. 1981). Canopy cover was estimated using a spherical densiometer (Hays et al. 1981).

Bird richness and relative bird abundance were calculated for each plot. Cedar Waxwings and American Goldfinches were excluded from the analysis because their flocking behavior tended to inflate estimates. Correlation analysis was used to examine associations between the habitat variables and bird richness and relative bird abundance. Analysis of variance (ANOVA) tests were used to compare differences among years for bird richness, relative bird abundance, and the habitat variables. If a significant difference was found with ANOVA, then Tukey's Studentized Range test was used to determine between year differences.

Results and Discussion

Means of bird richness, relative bird abundance, and habitat variables for the 41 habitat plots are summarized in Table 23. Both bird richness and relative bird abundance were significantly lower in 2004 than in 2002 ($P < 0.05$). In 2004, herbaceous cover was significantly greater than in 2002 ($P < 0.05$), while all other habitat variables were similar between the two years (all $P > 0.05$). There was a significant negative correlation between relative bird abundance and overstory tree density ($r = -0.14$, $P = 0.04$). A similar relationship was evident between bird richness and overstory tree density, although the correlation was not statistically significant ($r = -0.12$, $P = 0.09$). All other correlations between bird richness or relative bird abundance and the habitat variables were extremely low (all Pearson r, between -0.07 and 0.05; all $P > 0.05$).

Table 23. Means (SD) of bird richness, relative bird abundance, and habitat variables for 41, 25-m radius (0.2 ha) plots during 1994, 1998, 2000, 2002, and 2004.

	Year				
Variable	1994	1998	2000	2002	2004
Bird Richness	4.6 (2.1)b	4.0 (1.8)b	2.8 (1.9)a	3.7 (2.2)b	1.8 (1.9)a
Rel. Bird Abund.	6.6 (3.0)a	5.2 (2.8)a	3.4 (2.3)ab	4.4 (2.7)a	2.2 (1.6)b
Herb. Cov. (%)	60.0 (17.5)a	53.9 (20.6)a	52.4 (17.9)a	28.1 (15.6)b	48.5 (18.7)a
Shrub Thick. (%)	35.2 (15.9)ab	28.5 (14.7)b	38.9 (17.7)a	25.9 (16.7)ab	32.6 (12.0)b
Canopy Cov. (%)	59.2 (23.8)	45.4 (21.8)	51.7 (25.0)	45.6 (26.5)	47.4 (26.0)
Understory dens. (no./0.2 ha)	11.5 (15.3)	6.3 (18.8)	21.7 (27.1)	18.5 (30.2)	22.2 (31.0)
Overstory dens. (no./0.2 ha)	7.1 (13.9)a	7.6 (13.8)a	10.8 (20.5)ab	8.9 (16.0)ab	21.8 (40.1)b

Note: Values followed by the same or no letters within a row are not significantly different ($P > 0.05$).

The negative trends in bird richness and relative bird abundance in the habitat plots support the results of the breeding bird surveys. As discussed in the Results and Discussion of the Bird Survey section of this report, the declines in bird richness and relative bird abundance are related to loss of habitat due the large proportion of the site with standing water. In addition, the negative correlations found between bird richness and relative bird abundance and overstory tree density also help to explain the declines in species that require early-successional habitats. These declines in early-successional species are likely to continue as succession proceeds and overstory tree densities increase across the site.

In 2002, significant reductions in herbaceous cover and shrub thickness reflected high levels of disturbance of the interior of Tulula that occurred during restoration activities. These habitat changes were accompanied by significant increases in bird richness and relative bird abundance as a result of generalist species colonizing the site. Many of the generalist species that experienced large increases in 2002, such as the American Robin, Rufous-sided Towhee, and Song Sparrow, declined dramatically in 2004 as a result of the site being flooded by beaver (Table 22). The significant increase in herbaceous cover in 2004 compared to 2002 reflects the large increase in areas with standing water colonized by sedges and rushes. Observations during surveys indicated that few bird species use this rush/sedge dominated habitat, with the exception of a few blackbirds and wood ducks.

Bird surveys and habitat analyses are scheduled for 2006 to continue monitoring the responses of bird populations to post-restoration habitat changes. Results reported here indicate that some type of management is needed at Tulula to maintain the productivity of the habitat for birds (especially the habitat of the interior of the site). Management objectives should include taking appropriate actions to eradicate beaver or control the flooding caused by beaver, and maintaining a variety of early-successional habitat types.

DISCUSSION

Tulula continues to change as restoration proceeds and as natural processes respond to changing site conditions. We have developed a fairly comprehensive understanding of annual and seasonal variability in the structural and functional attributes of this restoration project.

The overall pattern of the restored stream channel has not changed since water was released in the first restored section in September 2001. We have noticed isolated areas of bank and bed erosion, but the channel is performing remarkably well after two years of water flow. Most of the notable areas of bank erosion are associated with beaver dams at the lower end of the site in the past year. Banks have eroded behind the dams and at the point of water entry back into the restored channel. After two years of water flow, bankfull widths did not change. However, we anticipate an increase in erosion problems during subsequent channel surveys in the middle and the lower end of the site due to beaver activity. Most of the channel has degraded to some extent, as noted by increasing cross-sectional areas of riffles and pools.

Changes in site hydrology were noted through the network of manual and electronic wells. The data from manual wells provide a more comprehensive understanding of changes in hydrology. Differences that suggest an improvement in hydrology (rise in water table depth) were observed with manual wells located in the floodplain close to the restored channel. Restoration of Tulula Creek did not appear to influence the hydrology of the fen. The assessment of site hydrology has been made more difficult from overbanking of water from beaver dams at the lower end of the site.

Restoration has had a clear influence on the composition of some plant communities. For example, restored wetland areas contained fewer species than unrestored areas or restored dry areas, and the species that dominated the restored wet areas were OBL and FACW plants. In restored areas that did not benefit from hydrologic change, soil disturbance led to a great increase in species richness. The production of both vegetative and reproductive stems of a common rush was influenced by both restoration and hydrologic change.

Natural succession continued to change the composition of wetland plant communities across the site, increasing the number and dominance of woody species. Although red maple continued to dominate the canopy of a forested fen that we have studied since 1994, the importance of white pine in the canopy increased. Had the water table in the fen increased after restoration, this increase in white pine may not have occurred. Red maple saplings continued to flourish in open areas of the site, with naturally-regenerating saplings outperforming nursery-stock saplings that were planted in 1995.

We found that the least disturbed plant communities (particularly red maple) had the quickest decomposition, the greatest amount of litter microarthropods, the most soil organic carbon, and the lowest soil pH. We conclude that soil characteristics related to low disturbance, rather than the presence of a closed canopy, probably have the greatest influence on speed of decomposition and numbers of litter microarthropods. Therefore, the most intact ecosystems appear to be functioning at the healthiest levels.

Researchers have rarely conducted long-term studies of vertebrates to determine changes in community assemblages, or to document population resilience and viability following the creation of breeding habitats at restoration sites. This information is critical for setting realistic time frames and criteria for assessing restoration success. Our project is yielding important information concerning the long-term dynamics of restored wetlands and the response of resident amphibians to environmental perturbations. The data will be useful in designing more meaningful assessment criteria for future restoration projects throughout the eastern U.S.

To enhance population resilience, we used a metapopulation design that involved the creation of a large array of breeding sites that differed in size, depth, and hydroperiod. Many ponds were unproductive in certain years because of premature drying associated with drought, the outbreak of a deadly viral disease, and the invasion of ponds by fish due to beaver activity and site reconstruction. Despite catastrophic mortality in most ponds each year, a few ponds have produced juveniles annually, and total juvenile output has been sufficient to maintain viable adult populations of resident species. The extent to which *Ranavirus* and predatory fish will ultimately impact adult populations of the wood frog and spotted salamander will become more clear as we continue to track changes in breeding population size in 2004 and beyond. However, the data to date indicate the wetland design at Tulula has resulted in populations that are resilient to major site perturbations associated with drought, disease, and predators.

The significant declines in bird species richness and relative bird abundance in 2004 were associated with substantial amounts of standing water in the interior of the floodplain due to flooding by beaver. Habitat productivity for birds in these areas generally decreased as the structure of the habitat became more homogenous, being dominated by a thick cover of low-growing rushes and sedges. Most affected by the flooding were species that require early-successional habitats; most notably many Neotropical migrants of conservation concern including the Golden-winged Warbler, Chestnut-sided Warbler, Hooded Warbler, and Yellow-breasted Chat.

Tulula is the first wetlands mitigation bank in the Blue Ridge Province of North Carolina. Most mitigation banks in North Carolina are located in the Coastal Plain, and are considerably different from Tulula in terms of their hydrology and ecology. Our database on hydrology, soils, flora, and fauna continues to provide a framework for documenting the success of restoration at Tulula. These data were important in the development and design of restoration strategies, and have influenced considerations for site management. Tulula has provided research experience to more than 50 undergraduates at UNCA, including numerous senior research projects.

RECOMMENDATIONS

1. Beaver dams are exerting a localized but significant impact on bank erosion of the restored channel and are influencing the water table of nearby wetlands. Evaluating the geomorphology and stability of the restored stream channel and site hydrology will require controlling of beaver activity.

2. Eradicating or controlling beaver activity will also maintain or restore the productivity of the habitat for amphibians and birds by controlling or eliminating flooding in key portions of the site.

3. Future site management of the Tulula site should include efforts to retain portions of the site in an early successional stage (for example, using bush-hogging or burning). This would enhance habitat for small but unique plants that are presently being outcompeted, and for uncommon animals such as the Golden-winged Warbler.

4. Monitoring of floral and faunal communities at Tulula should continue, to document how they respond to the hydrologic changes. Ideally, a long-term monitoring program should be developed to gauge the success of the wetlands restoration over a decade or longer.

5. As the site re-establishes as a wetland, it should be monitored for the presence of invasive plant species such as cattail (*Typha latifolia*). Cattails are present in small numbers in some of the wettest habitats, but have the potential to dominate these areas, causing a local decline in species diversity.

LITERATURE CITED

Anderson, J.T. and L. M. Smith. 2002. The effect of flooding regimes on decomposition of *Polygonum pensylvanicum* in playa wetlands (Southern Great Plains, USA). Aquatic Botany 74:97-108.

Battle, J.M. and S.W. Golladay. 2001. Hydroperiod influence on breakdown of leaf litter in Cypress-gum wetlands. American Midland Naturalist 146:128-145.

Bervin, K. A. 1982. The genetic basis of altitudinal variation in the wood frog *Rana sylvatica*: An experimental analysis of life history traits. Evolution 36:962-983.

Binkley, D., D. Richter, M. B. David, and B. Caldwell. 1992. Soil chemistry in a loblolly/longleaf pine forest with interval burning. Ecological Applications 2:157-164.

Bonham C. D. 1989. Measurement of terrestrial vegetation. John Wiley & Sons, Inc., New York, New York. 478 pp.

Braccia, A. and D.P. Batzer. 2001. Invertebrates associated with woody debris in a southeastern U.S. forested floodplain wetland. Wetlands 21:18-31.

Coleman, D. and D. A. Crossley, Jr. 1996. Fundamentals of soil ecology. San Diego: Academic Press. 205 pp.

Crawley, M.J. 1993. GLIM for ecologists. Oxford: Blackwell Science. 379 pp.

Daszak, P., L. Berger, A. A. Cunningham, A. D. Hyatt, D. E. Green and R. Speare. 1999. Emerging infectious diseases and amphibian population declines. Emerging Infectious Diseases 5:1-14.

FISRWG (1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the U.S. government). GPO Item No. 0120-A.

Franzreb, K. E., and R. A. Phillips. 1996. Neotropical migratory birds of the southern Appalachians. U.S. Forest Service, Gen. Tech. Rep. SE-96, Asheville, North Carolina.

Gill, D. E. 1978. The metapopulation ecology of the red-spotted newt, *Notophthalmus viridescens* (Rafinesque). Ecological Monographs 48:145-166.

Hamel, P. B. 1992. The land manager's guide to the birds of the south. The Nature Conservancy, Southeast Region, Chapel Hill, North Carolina. 437 pp.

Harcombe, P. A. 1987. Tree life tables. BioScience 37:557-568.

Hays, R. L., C. Summers, and W. Seitz. 1981. Estimating wildlife habitat variables. U.S. Fish and Wildlife Service. FWS/OBS-81-47. 111 pp.

Kartesz, J.T. 1994. A synonomized checklist of the vascular flora of the United States, Canada, and Greenland. Timber Press, Portland, OR.

Klaus, N. A. and D. A. Buehler. 2001. Golden-winged Warbler breeding habitat characteristics and nest success in clearcuts in the southern Appalachian mountains. Wilson Bulletin 113:297-301.

LeGand, H.E., Jr. and S.P. Hall. 2004. Natural Heritage Program list of the rare animal species of North Carolina. North Carolina Natural Heritage Program, Raleigh, NC. 91 pp.

Mallow, D. and D. A. Crossley, Jr. 1984. Evaluation of five techniques for recovering postlarval stages of chiggers (Acarine; Trombiculidae) from soil habitats. Journal of Economic Entomology 77:281-284.

McGraw, J. B. 1987. Seed bank properties of an Appalachian sphagnum bog and a model of the depth distribution of viable seeds. Canadian Journal of Botany 65:2028-2035.

Mooney, H. A. 1988. Lessons from Mediterranean-climate regions. *In* E. O. Wilson (ed.). Biodiversity. National Academy Press, Washington, D. C.

Moorhead, K. K. 2001. Seasonal water table dynamics of a southern Appalachian floodplain and associated fen. Journal of the American Water Resources Association 37:105-114.

Moorhead, K. K. 2003. Effects of drought on the water-table dynamics of a southern Appalachian mountain floodplain and associated fen. Wetlands 23:792-799.

Moorhead, K. K. and I. M. Rossell. 1998. Southern mountain fens. Pp. 379-403 *In*: M. G. Messina and W. H. Conner (eds). Southern Forested Wetlands: Ecology and Management. Lewis Publishers, Boca Raton, Florida.

Moorhead, K. K., I. M. Rossell, C. Reed Rossell, Jr., and J. W. Petranka. 2001a. Ecological Assessment of a Wetlands Mitigation Bank. Phase I: Ecological Conditions and Initial Restoration Efforts. Final Report to the Center for Transportation and the Environment. North Carolina State University, Raleigh, North Carolina.

Moorhead, K. K., I. M. Rossell, J. W. Petranka, and C. R. Rossell, Jr. 2001b. Tulula wetlands mitigation bank. Ecological Restoration 19:74-80.

Morrison, M. L. 1986. Bird populations as indicators of environmental change. Pp. 429-451 *In*: Current Ornithology. Vol. 3, R. F. Johnston (ed). Plenum Press, New York, New York.

Nelson, D. W. and L. E. Sommers. 1982. Total carbon, organic carbon, and organic matter. P. 539-579. In A. L. Page, R. H. Miller, and D. R. Keeney (eds). Methods of Soil Analysis, Part 2, 2nd ed. Agronomy Monograph 9, ASA and SSSA, Madison, WI.

North Carolina Department of Transportation. 1997. Stream and Wetland Mitigation Plan. Tulula Creek Wetlands Mitigation Bank Graham County, North Carolina. Raleigh, North Carolina.

North Carolina Department of Transportation. 2003. Annual Report for 2003. Tulula Bog Mitigation Site. Office of Natural Environment and Roadside Environmental Unit, Raleigh, NC.

North Carolina Natural Heritage Program. 1999. List of the rare plants of North Carolina. Division of Parks and Recreation, Raleigh, NC. 95 pp.

Noss, R. F. 1983. A regional landscape approach to maintain diversity. Bioscience 33:700-706.

Odum, E. P., J. E. Pinder III, and T. A. Christiansen. 1984. Nutrient losses from sandy soils during old-field succession. American Midland Naturalist 111:148-154.

Pechmann, J. H. K., R. A. Estes, D. E. Scott and J.Whitfield Gibbons. 2001. Amphibian colonization and use of ponds created for trial mitigation of wetland loss. Wetlands 21: 93-111.

Pendelton, G. W. 1995. Effects of sampling strategy, detection probability, and independence of counts on the use of point counts. Pp. 131-134. In: Monitoring bird populations by point counts. (eds. C. J. Ralph, J. R. Sauer, and S. Droege. U. S. Forest Service, Gen. Tech. Rep. PSW-GTR-149, Albany, California.

Petranka, J. W. 1998. Salamanders of the United States and Canada. Smithsonian Institution Press, Washington D. C. 587 pp.

Petranka, J. W., A. W. Rushlow, and M. E. Hopey. 1998. Predation by tadpoles of *Rana sylvatica* on embryos of *Ambystoma maculatum*: Implications of ecological role reversals by *Rana* (predator) and *Ambystoma* (prey). Herpetologica 54:1-13.

Petranka, J. W. and C. A. Kennedy. 1999. Pond tadpoles with generalized morphology: is it time to reconsider their functional roles in aquatic communities? Oecologia 120:621-631.

Petranka, J. W., C. A. Kennedy, and S. M. Murray. 2003a. Response of amphibians to restoration of a southern Appalachian wetland: a long-term analysis of community dynamics. Wetlands 23:1030-1042.

Petranka, J. W., S. M. Murray, and C. A. Kennedy. 2003b. Response of amphibians to restoration of a southern Appalachian wetland: perturbations confound post-restoration assessment. Wetlands 23: 278-290.

Radford, A. E., H. E. Ahles, and C. R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. University of North Carolina Press, Chapel Hill, NC.

Reynolds, Barbara C., D. A. Crossley, Jr., and Mark D. Hunter. 2003. Response of soil microarthropods to forest canopy inputs along a productivity gradient. Pedobiologia 47: 127-139.

Rosgen, D. 1996. Applied River Morphology. 2nd Edition. Wildland Hydrology, Pagosa Springs, Colorado.

Rossell, C. R.. Jr., I. M. Rossell, J. W. Petranka, and K. K. Moorhead. 1999. Characteristics of a partially disturbed southern Appalachian forest-gap bog complex. Pp. 81-89 *In*: R. P. Eckerlin (ed). Proceedings of the Appalachian Biogeography Symposium. Virginia Museum of Natural History Special Publication Number 7, Martinsville, Virginia.

Rossell, C. R., Jr. 2001. Song perch characteristics of Golden-winged Warblers in a mountain wetland. Wilson Bulletin 113:246-248.

Rossell, C. R., Jr., I. M. Rossell, M. M. Orraca, and J. W. Petranka. 2002. Epizootic disease and high mortality in a population of eastern box turtles. Herpetological Review 33:99-101.

Rossell, C.R., Jr., S.C. Patch, and S.P. Wilds. 2003. Attributes of Golden-winged Warbler territories in a mountain wetland. Wildlife Society Bulletin 31:1099-1104.

Rossell, I. M. 1996. Noteworthy collections from North Carolina: *Lilium canadense* ssp. *editorum* (Liliaceae). Castanea 61:196-197.

Rossell, I. M. and C. L. Wells. 1999. The seed banks of a southern Appalachian fen and an adjacent degraded wetland. Wetlands 19:365-371.

SAS Institute, Inc. 2001. Version 8.02 for Windows. SAS Institute, Inc. Cary, NC.

Seastedt, T.R. 1984. The role of microarthropods in decomposition and mineralization processes. Annual Review of Entomology 29:25-46

Semlitsch, R. D., Scott, D. E., Pechmann, J. H. K., and J. W. Gibbons. 1996. Structure and dynamics of an amphibian community: Evidence from a 16-year study of a natural pond. *In*: Long term studies of vertebrate communities. M. L. Cody and J. Smallwood (eds.). Academic Press.

Short, C. 1988. Mitigation Banking. Biological Report 88(41). U. S. Fish and Wildlife Service, Washington D.C.

Swift, M.J., Heal, O.W., and Anderson, J.M. 1979. Decomposition in Terrestrial Ecosystems. University of California, Berkeley, CA 372 pp.

Thunhorst, G.A. 1993. Wetland planting guide for the northeastern United States – plants for wetland creation, restoration, and enhancement. Environmental Concern, Inc., St. Michaels, MD. 179 pp.

U.S. Department of Agriculture. 2001. The PLANTS database, Version 3.1. National Plant Data Center, Baton Rouge, LA: (http://plants.usda.gov).

U.S. Fish and Wildlife Service. 1996. The 1996 national list of vascular plant species that occur in wetlands. U.S. Fish and Wildlife Service, Washington, D.C. 209 pp.

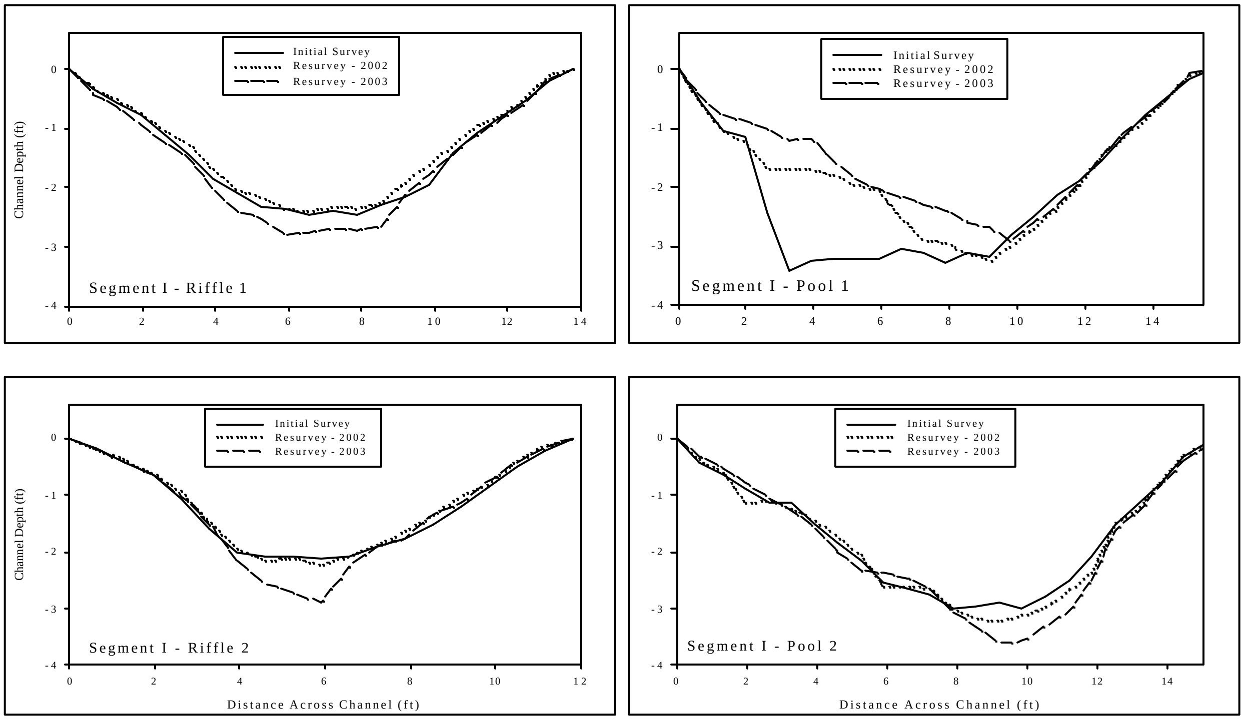
Warren, R.J., II., I. M. Rossell, and K.K. Moorhead. 2004. Colonization and establishment of red maple (*Acer rubrum*) in a southern Appalachian wetland. Wetlands 24:364-374.

Weakley, A. S. 2000. Flora of Carolinas and Virginia (working draft). The Nature Conservancy, Southern Resource Office, Durham, NC. 898 pp.

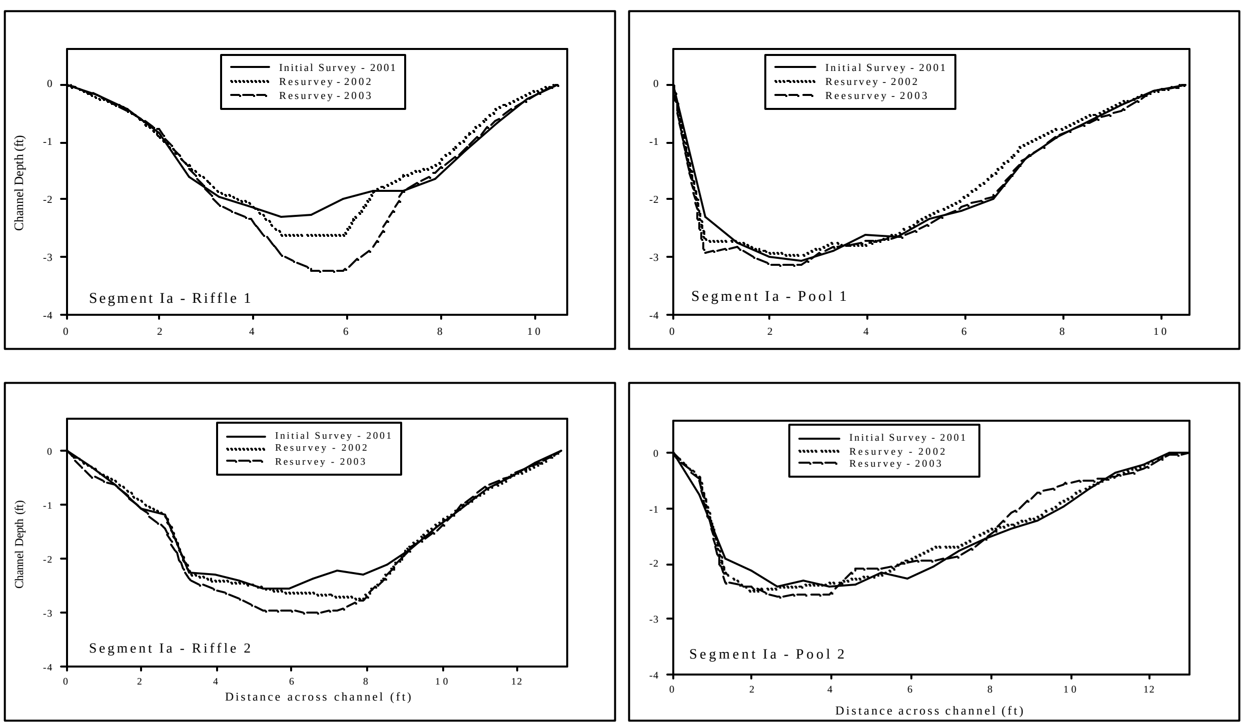
Weakley, A. S. and M. P. Schafale. 1994. Non-alluvial wetlands of the southern Blue Ridge -- diversity in a threatened ecosystem. Water, Air, and Soil Pollution 77:359-383.

Wilbur, R. B. and N. L. Christensen. 1983. Effects of fire on nutrient availability in a North Carolina Coastal Plain pocosin. American Midland Naturalist 110:54-61.

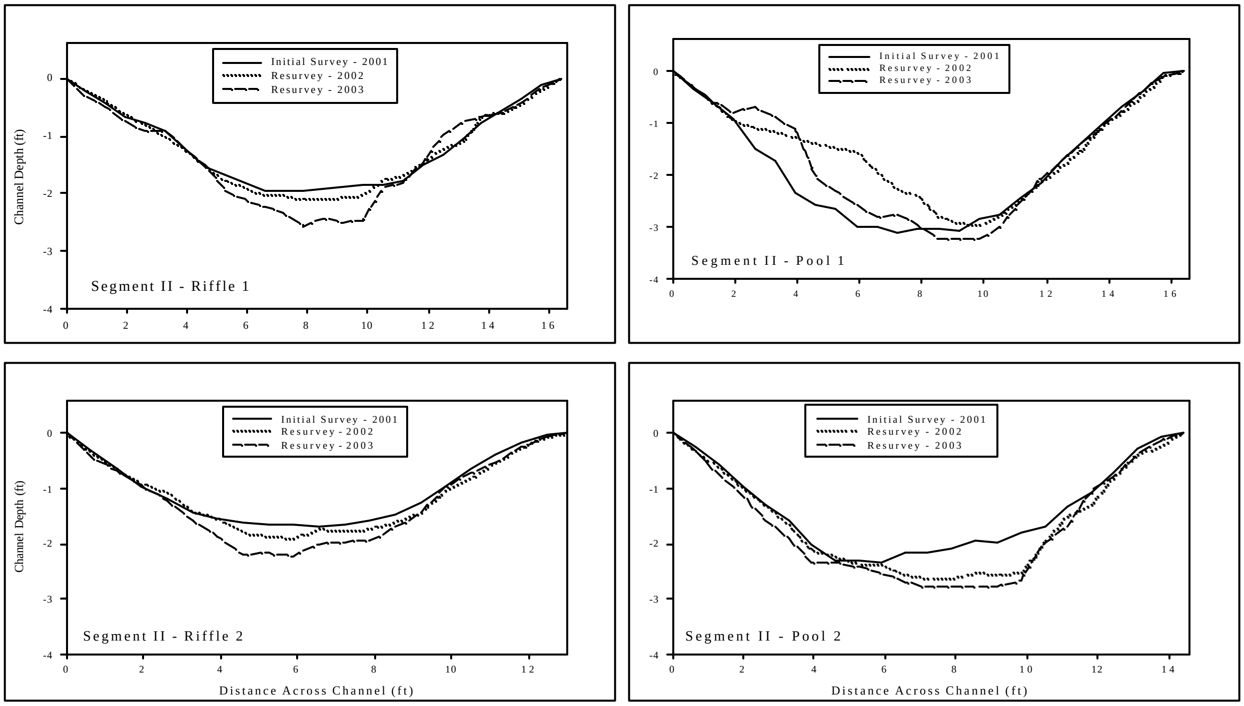
Appendix A1. Cross-sections of riffles and pools in stream segment I.



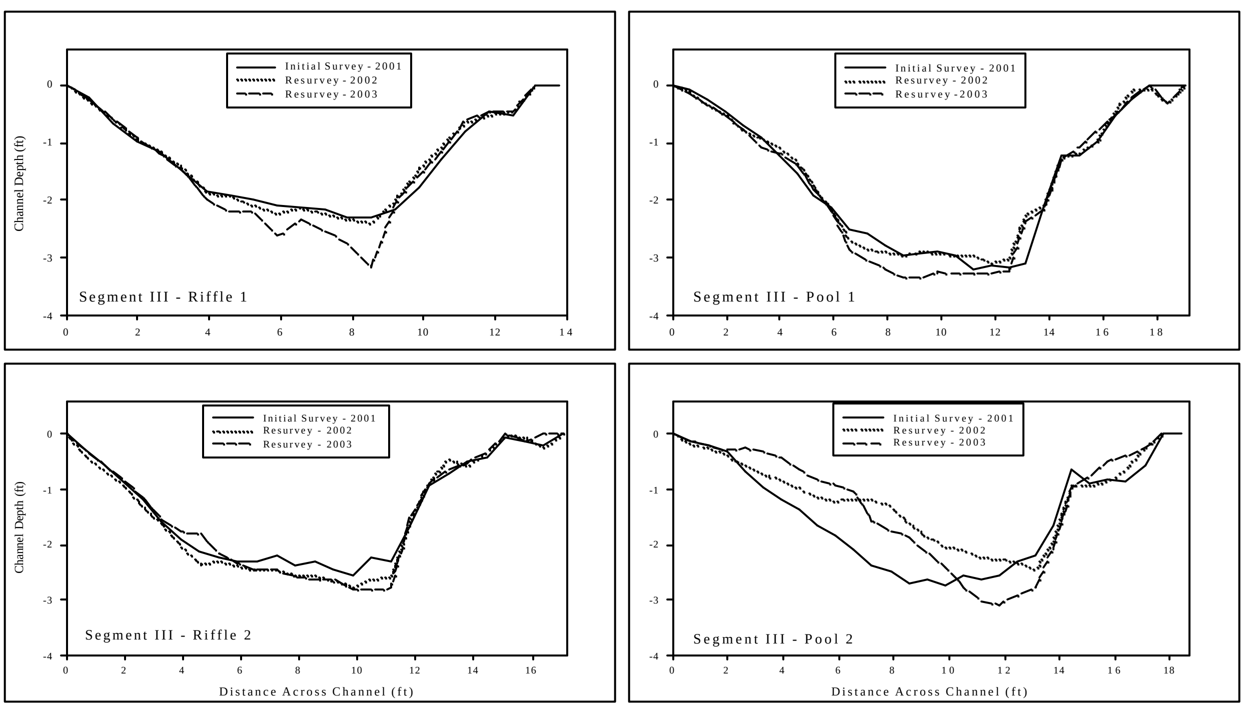
Appendix A2. Cross sections of riffles and pools in stream segment Ia.



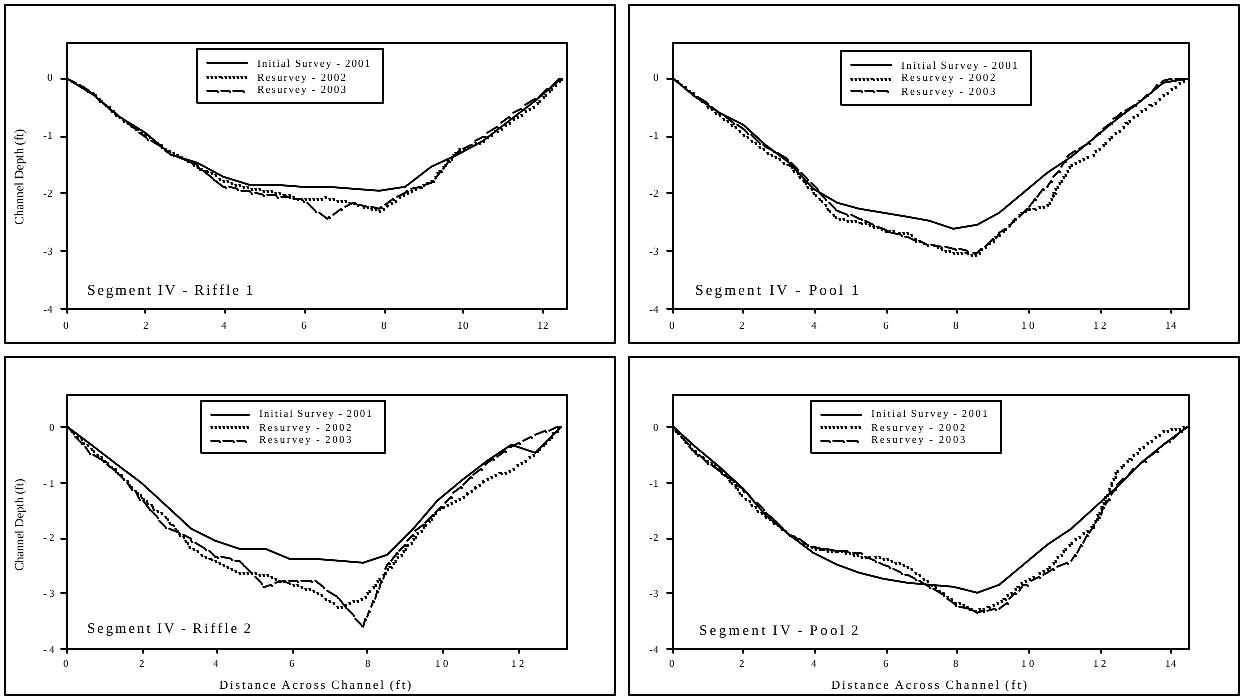
Appendix A3. Cross sections of riffles and pools in stream segment II.



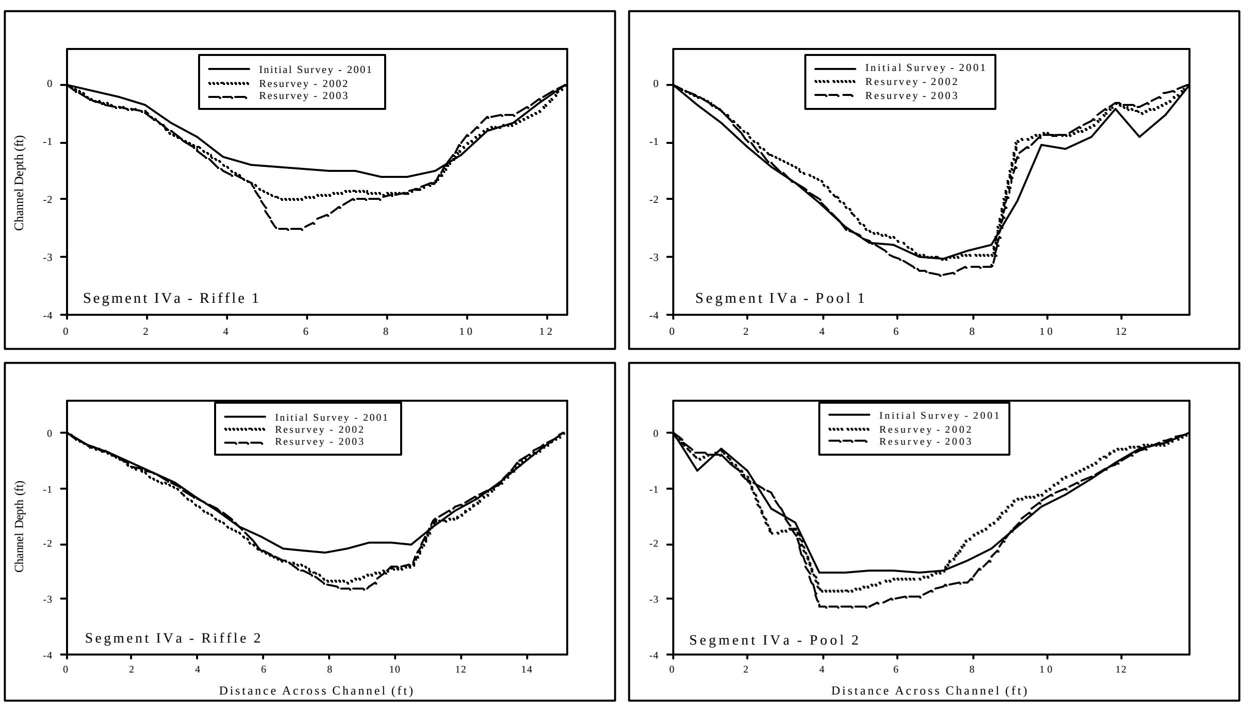
Appendix A4. Cross sections of riffles and pools in stream segment III.



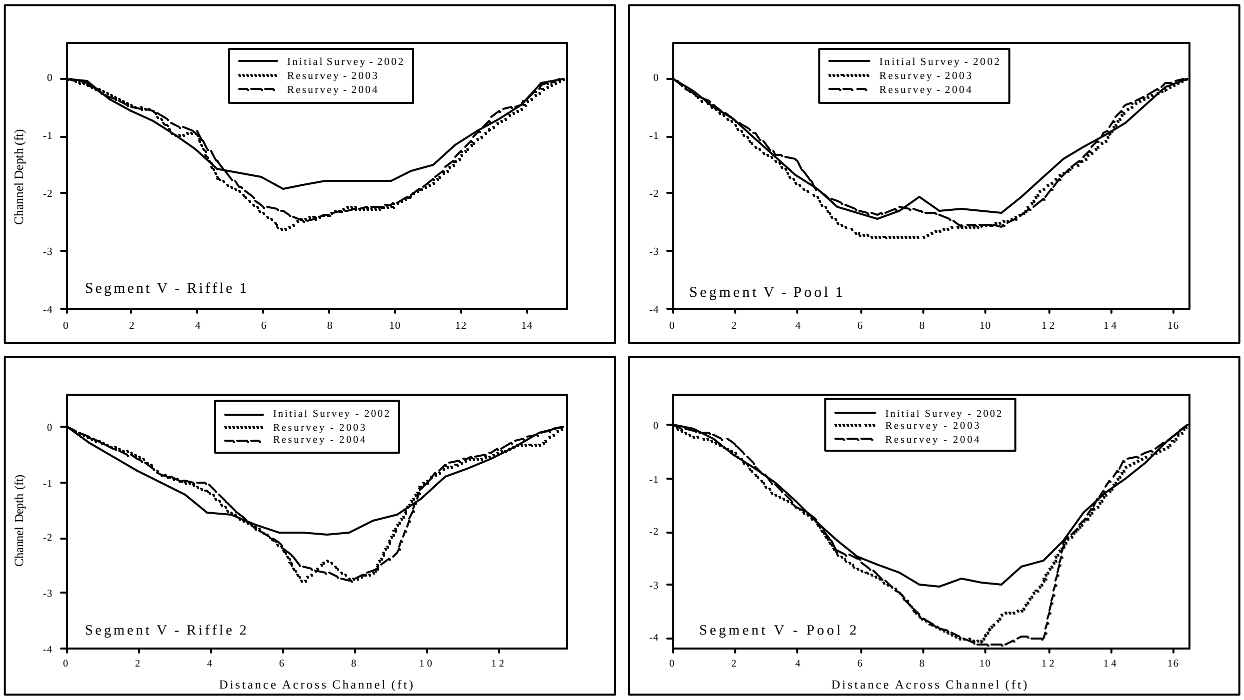
Appendix A5. Cross sections of riffles and pools in stream segment IV.



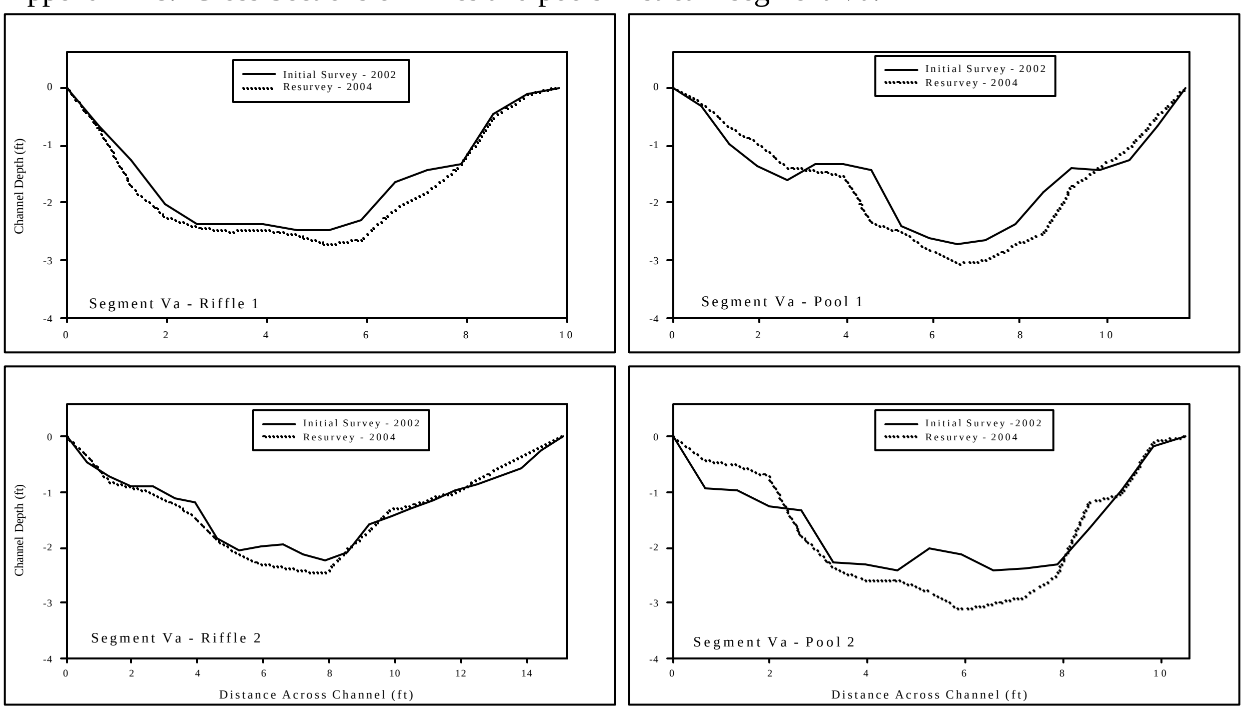
Appendix A6. Cross sections of riffles and pools in stream segment IVa



Appendix A7. Cross sections of riffles and pools in stream segment V.

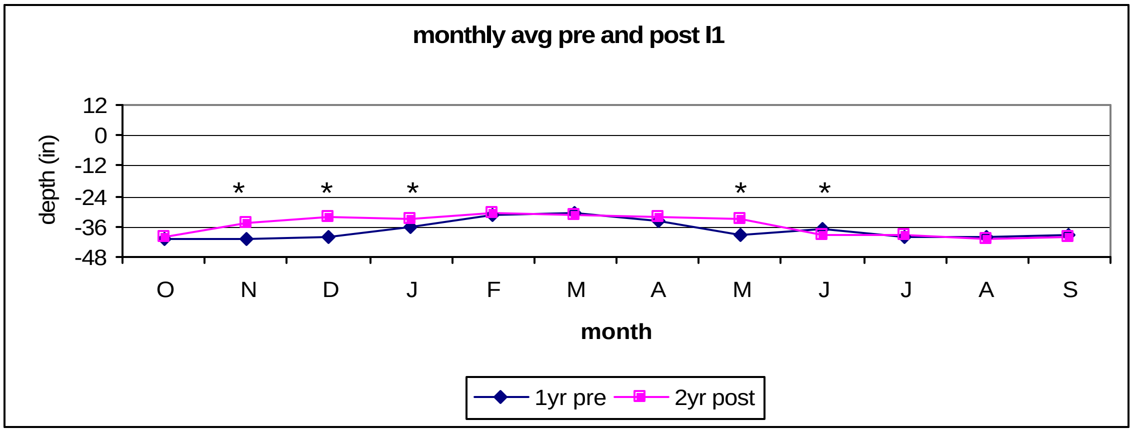


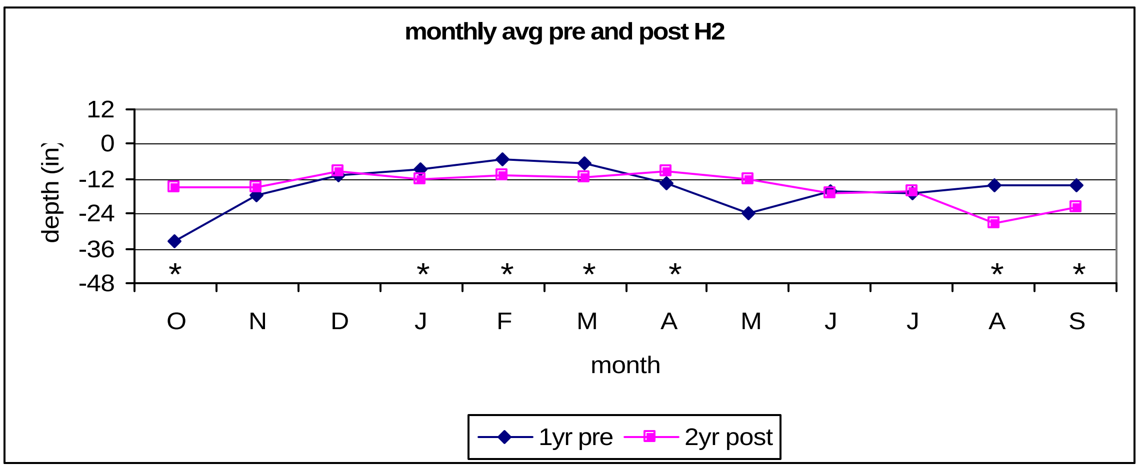
Appendix A8. Cross Sections of riffles and pools in stream segment Va.

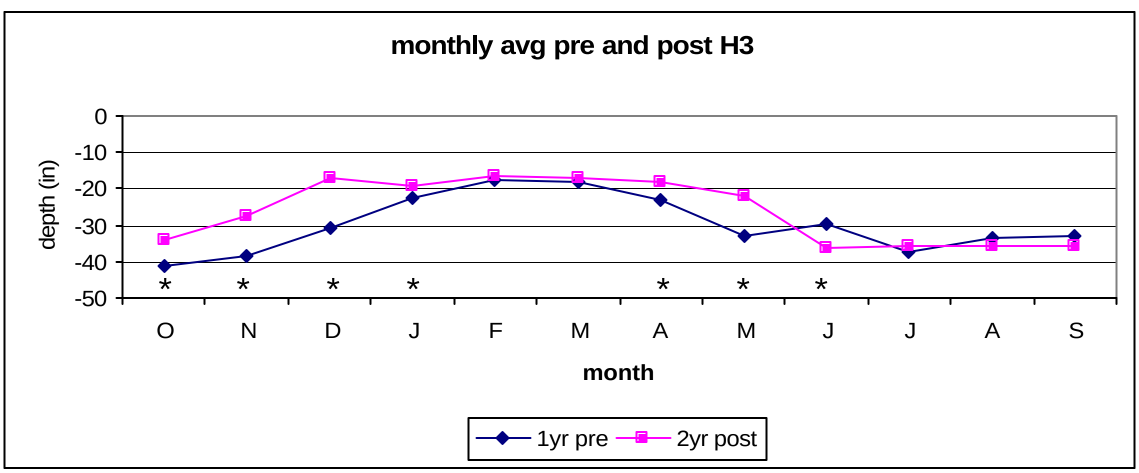


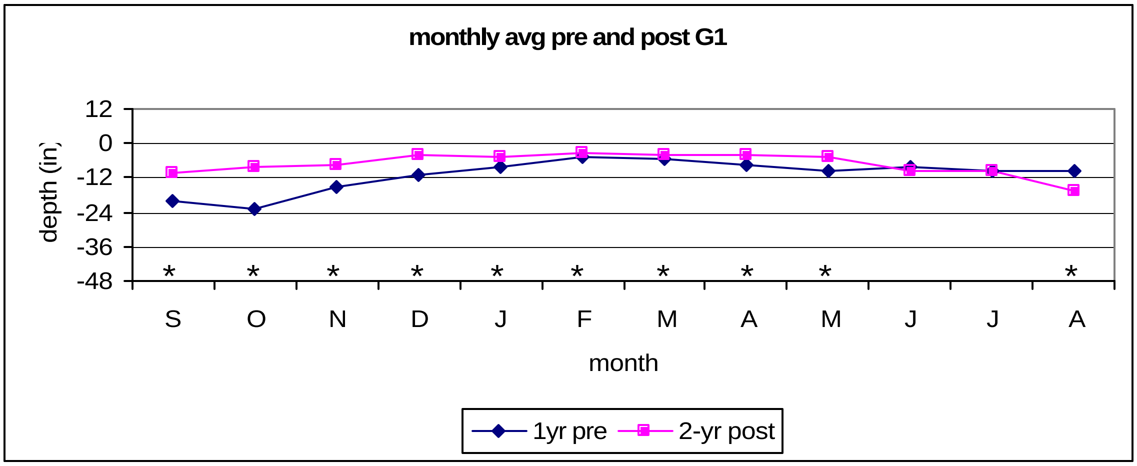
Appendix B. Water-table data for electronic wells (see Fig. 3 for well location). Months with asterisks are significantly different.

B1. Pre- and post-restoration water-table data from the electronic wells of stream Section I.








monthly avg pre and post G1
depth (in)
12
0
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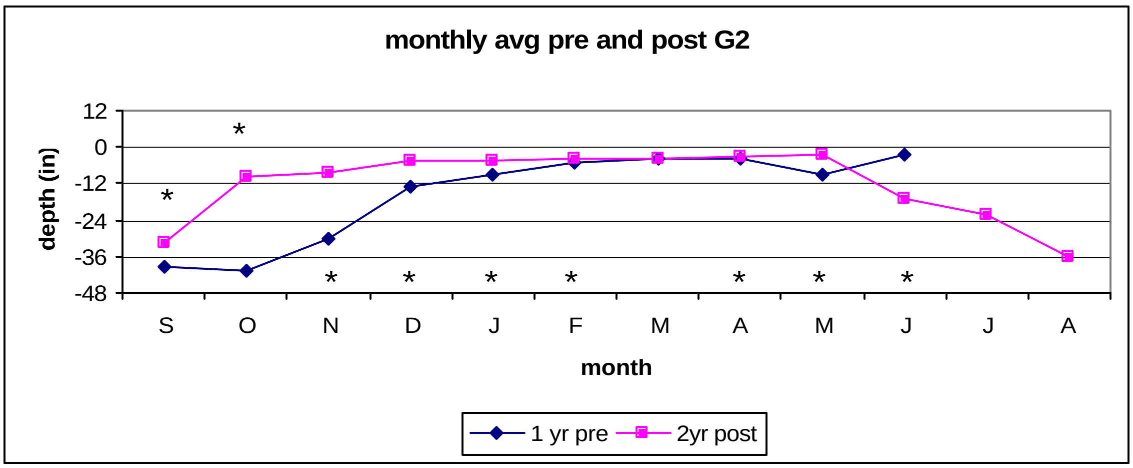
A
month
1yr pre
2-yr post


monthly avg pre and post G2
depth (in)
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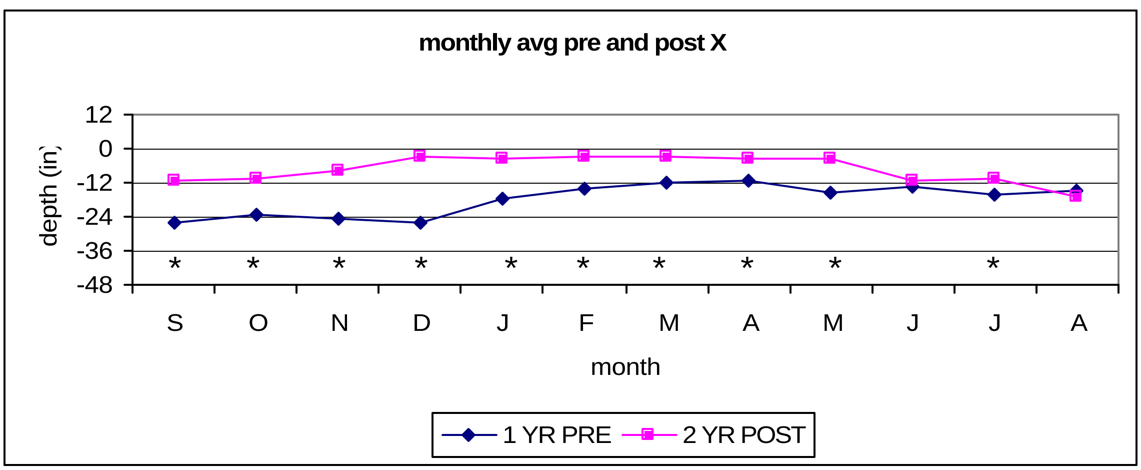
2yr post


monthly avg pre and post X
depth (in)
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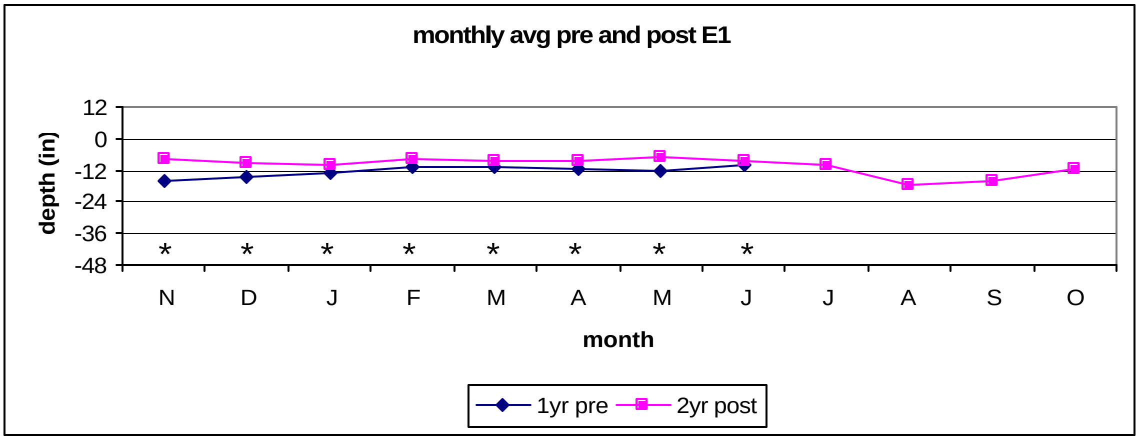
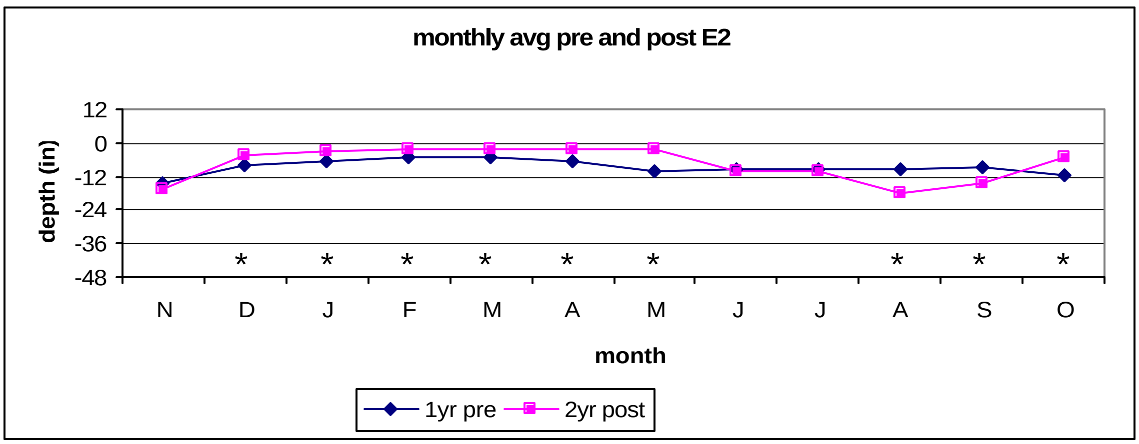
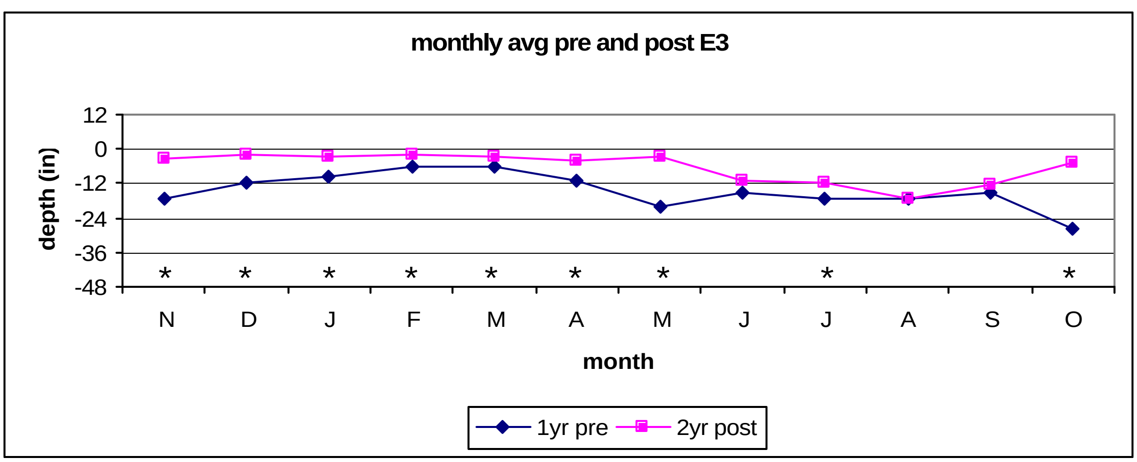
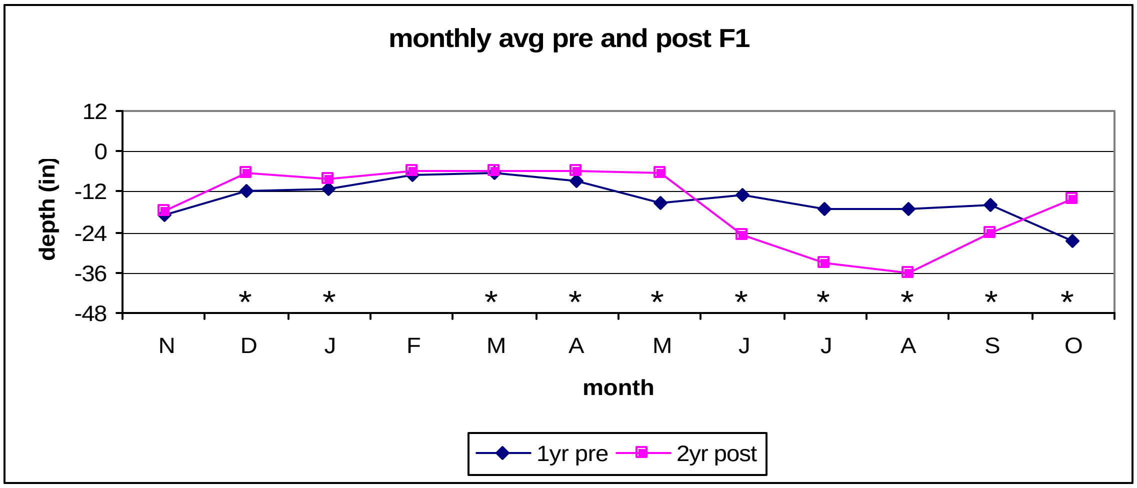
month
1 YR PRE
2 YR POST

B2. Pre- and post-restoration water-table data from the electronic wells of Section II and III.








monthly avg pre and post F1
depth (in)
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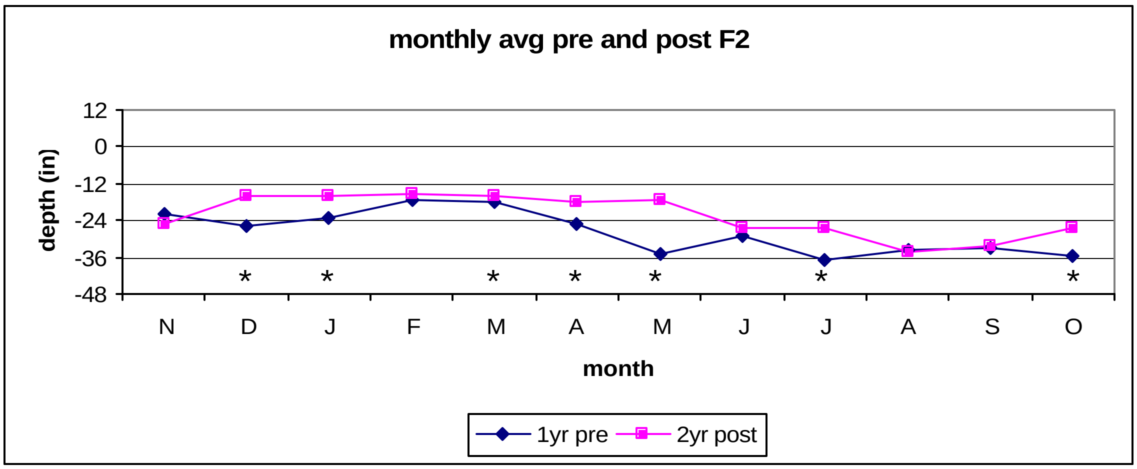
N D J F M A M J J A S O
month
1yr pre
2yr post


monthly avg pre and post F2
depth (in)
12
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-12
-24
-36
-48
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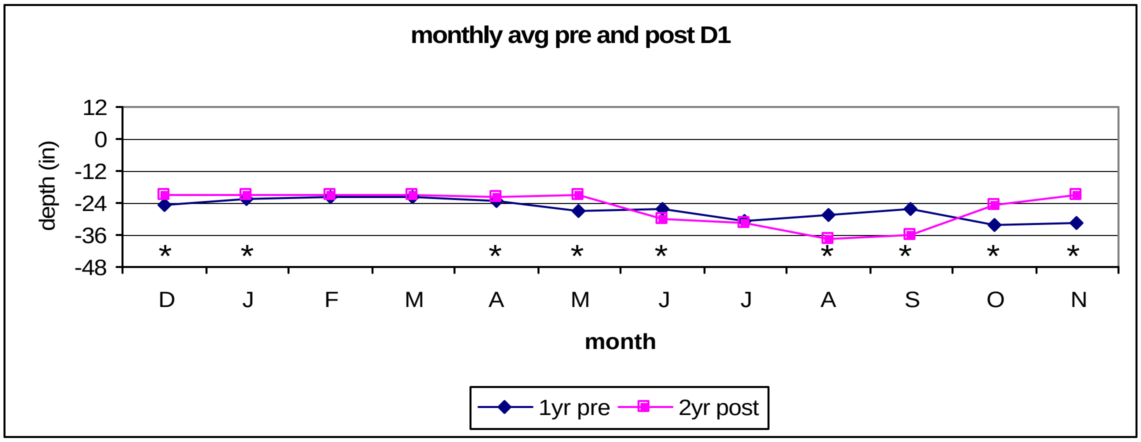
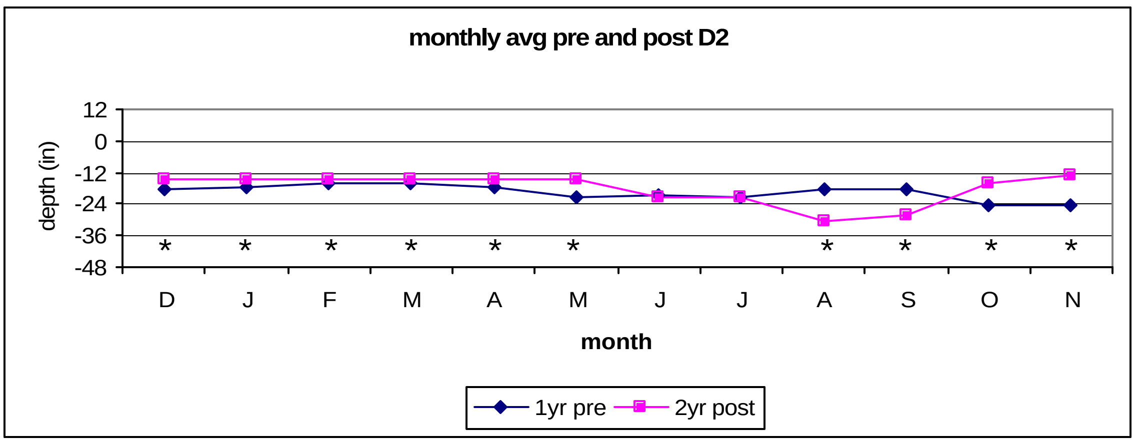
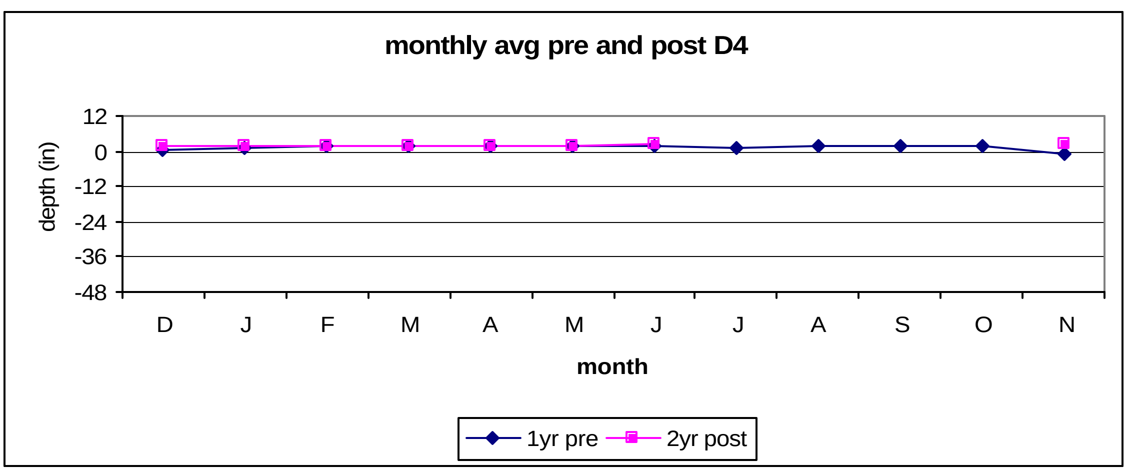
N D J F M A M J J A S O
month
1yr pre
2yr post

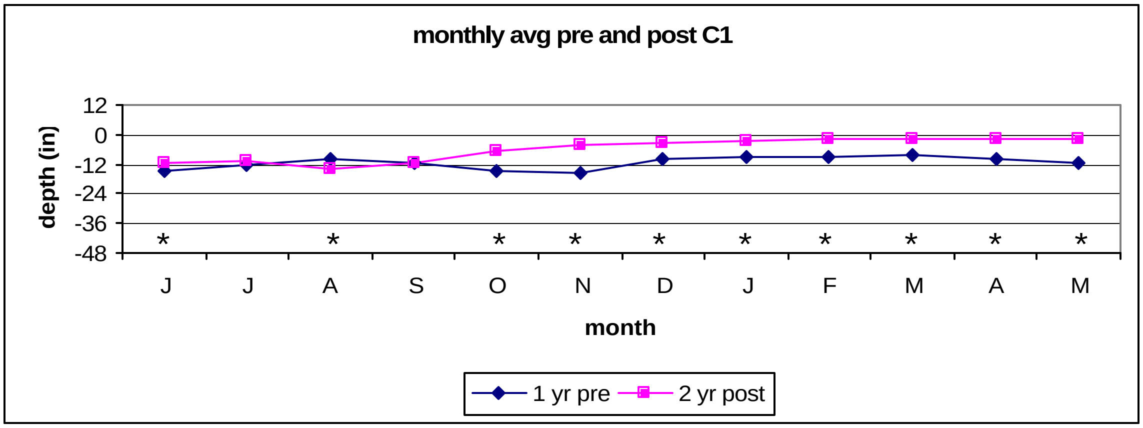
B3. Pre- and post-restoration water-table data from the electronic wells of Section IV.

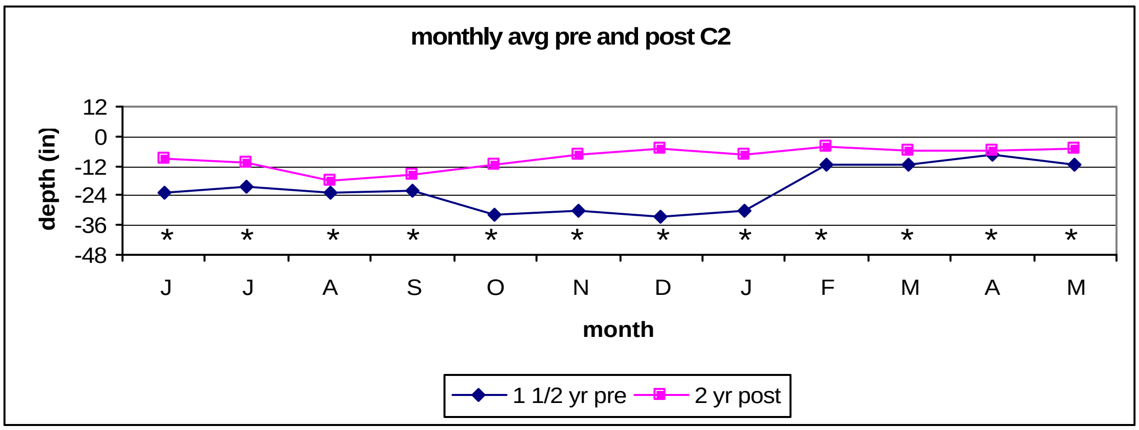


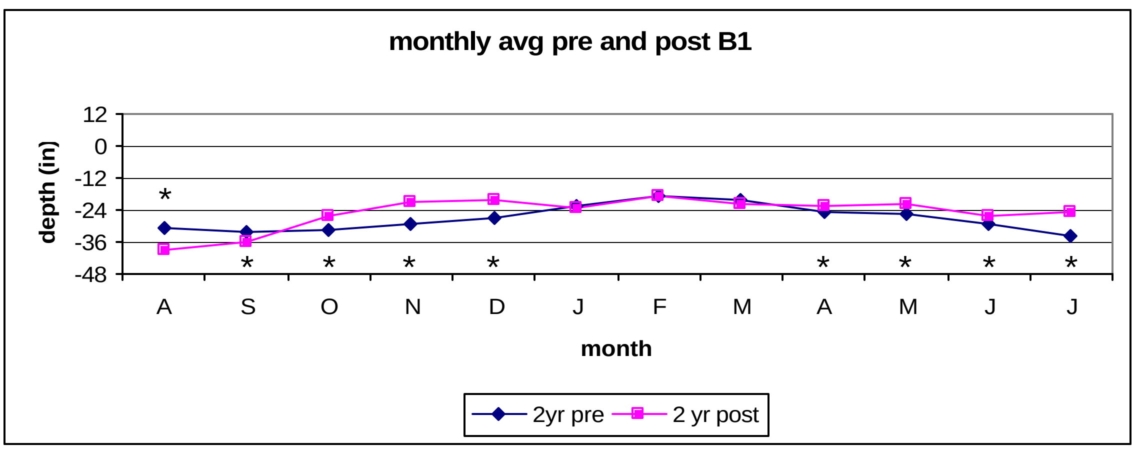


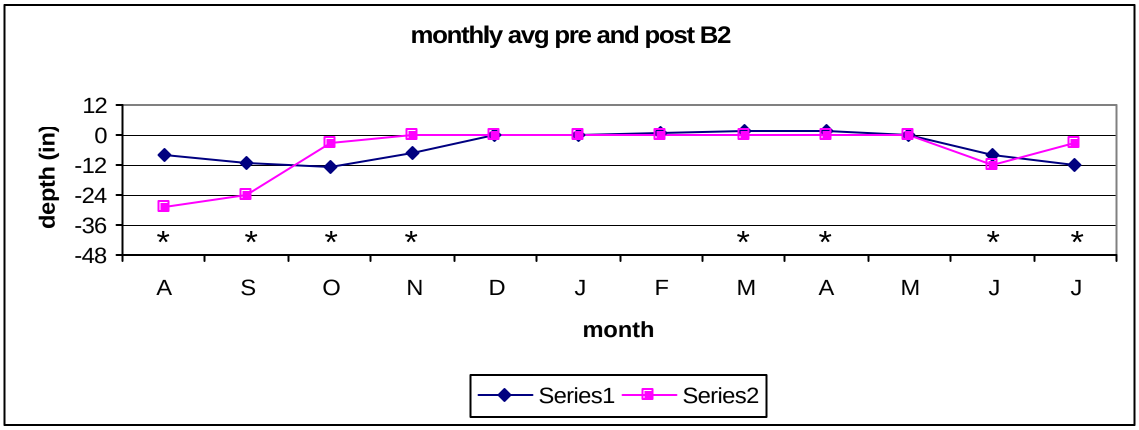


B4. Pre- and post-restoration water-table data from the electronic wells of Section V and Va.








monthly avg pre and post B2
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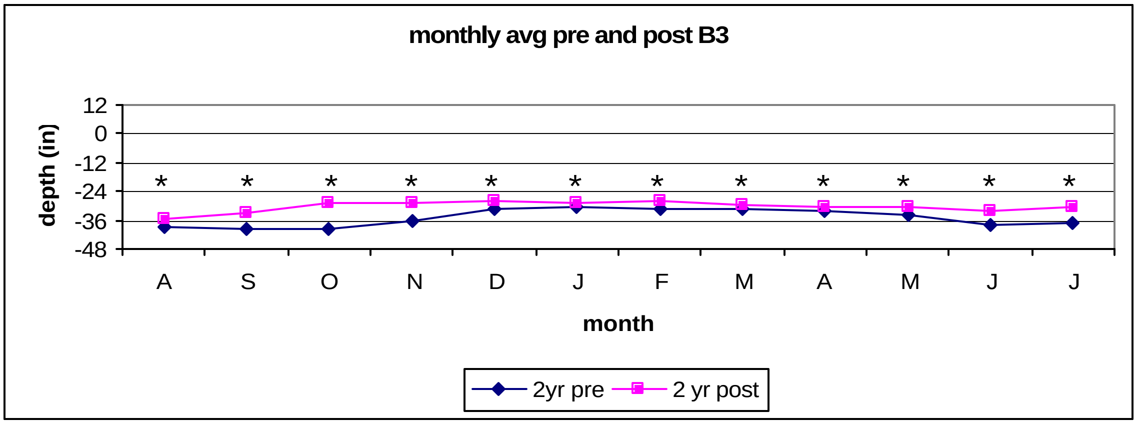
A S O N D J F M A M J J
month
Series1
Series2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depth (in)
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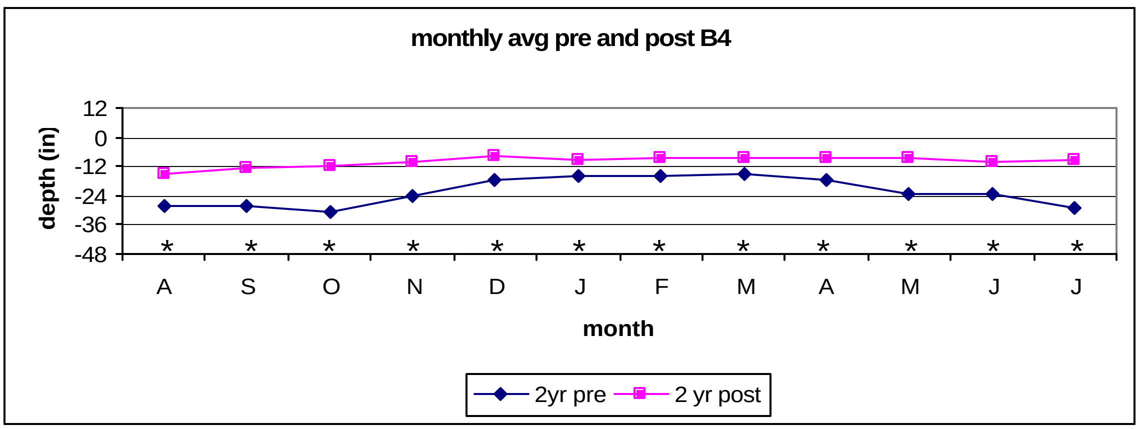
A S O N D J F M A M J J
month
2yr pre
2 yr post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depth (in)
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-48
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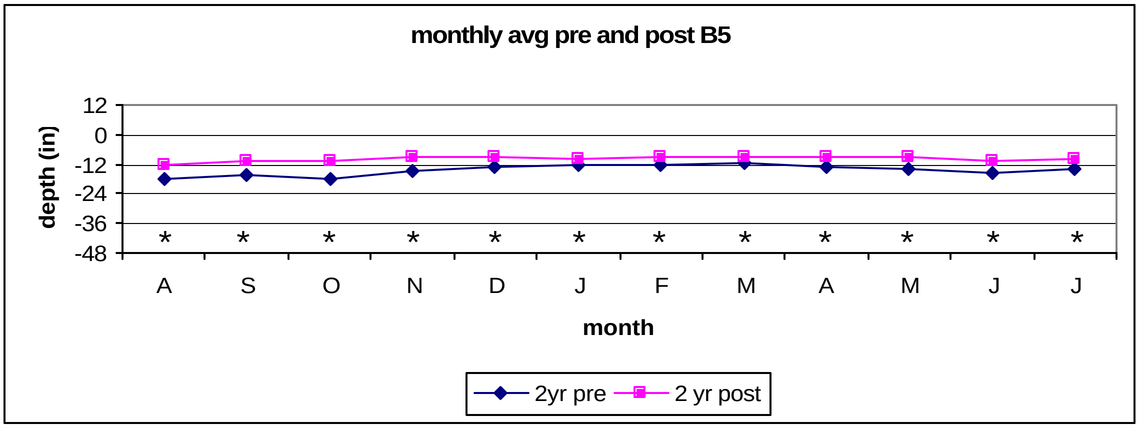
A S O N D J F M A M J J
month
2yr pre
2 yr post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depth (in)
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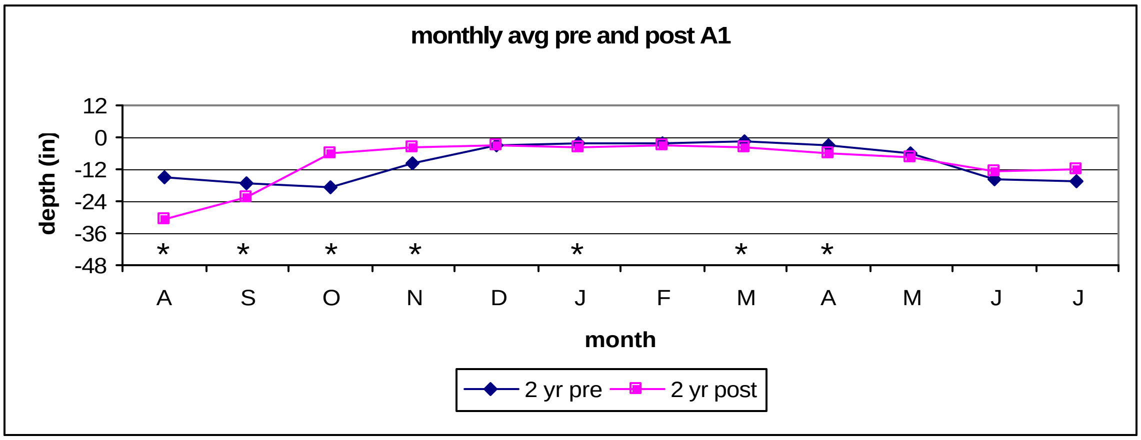
A S O N D J F M A M J J
month
2yr pre
2 yr post


monthly avg pre and post A1
depth (in)
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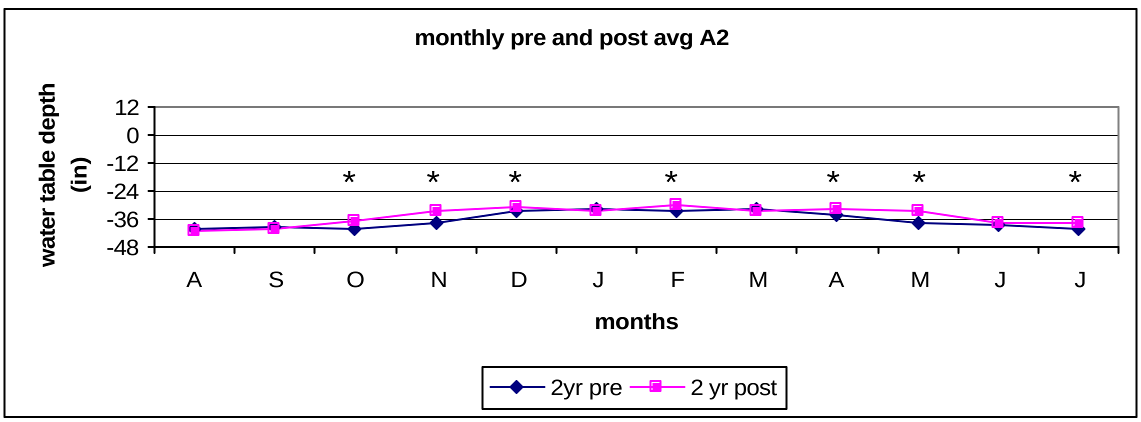
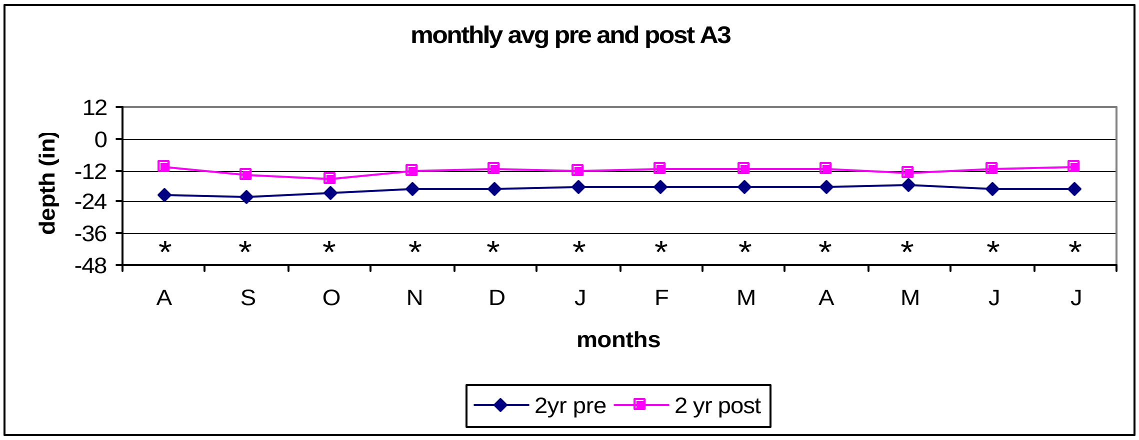
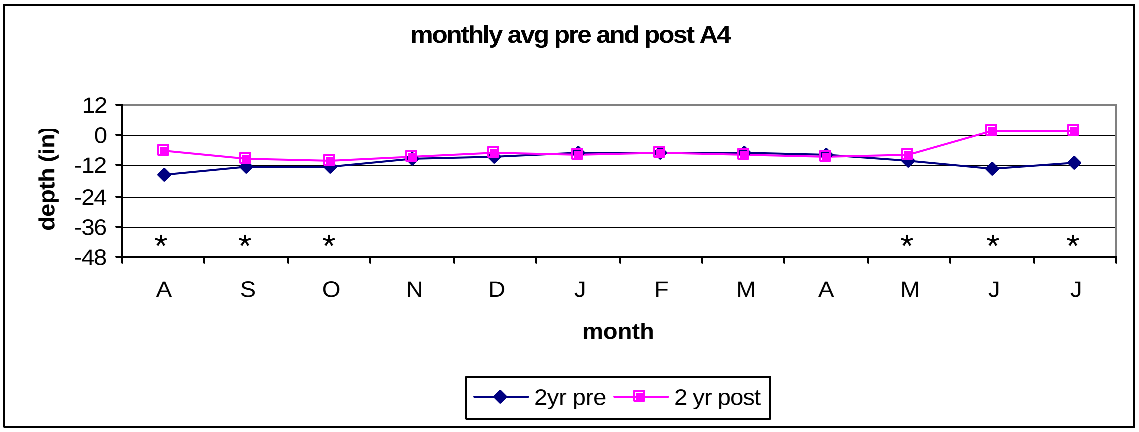
A S O N D J F M A M J J
month
2 yr pre
2 yr post


monthly pre and post avg A2
water table depth (in)
12
0
-12
-24
-36
-48
* * * * * * *
A S O N D J F M A M J J
months
2yr pre
2 yr post



monthly avg pre and post A3
depth (in)
12
0
-12
-24
-36
-48
* * * * * * * * * * * *
A S O N D J F M A M J J
months
2yr pre
2 yr post

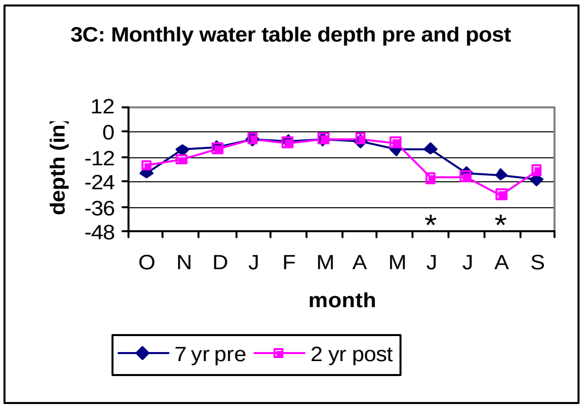


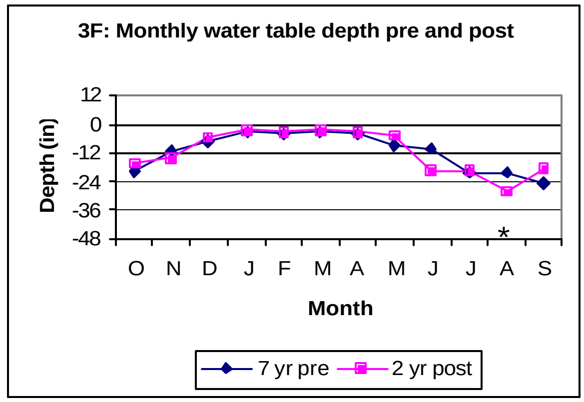
monthly avg pre and post A4
depth (in)
12
0
-12
-24
-36
-48
* * * * * *
A S O N D J F M A M J J
month
2yr pre
2 yr post

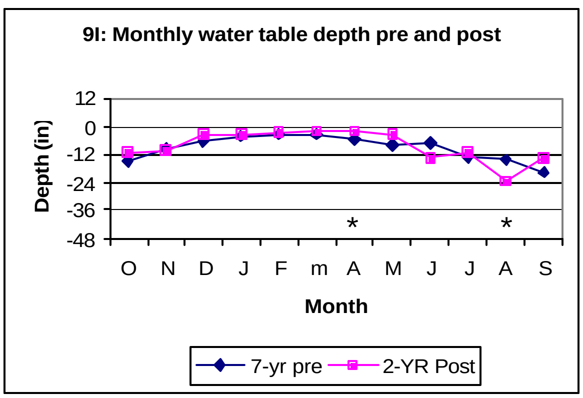
Appendix C. Water-table data from manual wells (see Fig. 3 for location of site location of wells). Months with asterisks are significantly different.

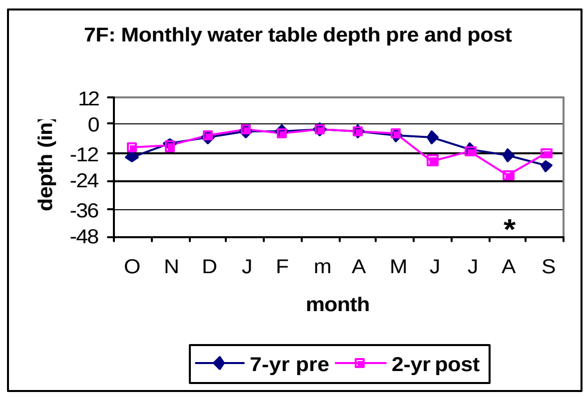
C1. Pre- and post-restoration water table from manual wells located on the eastern side of Tulula.

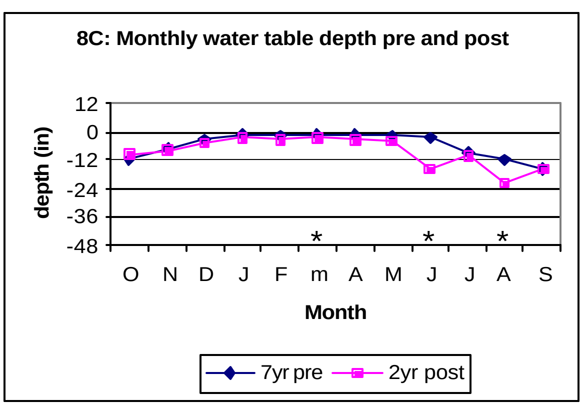
C1a. Six manual wells in Tulula fen.

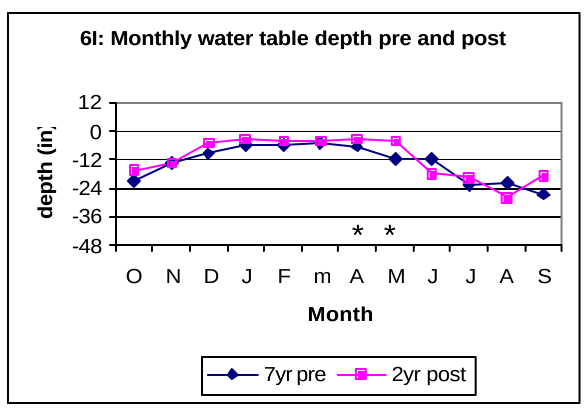




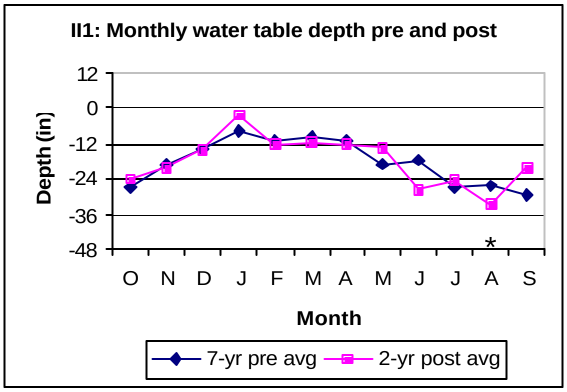


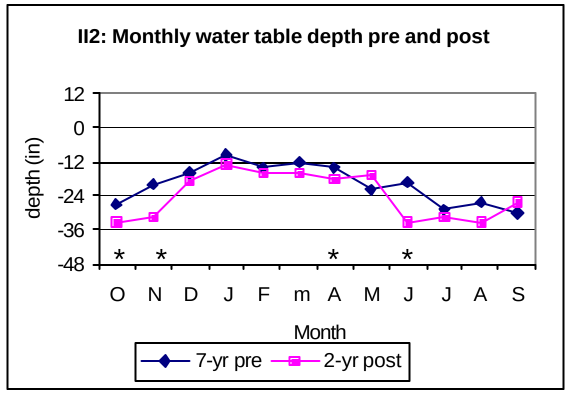


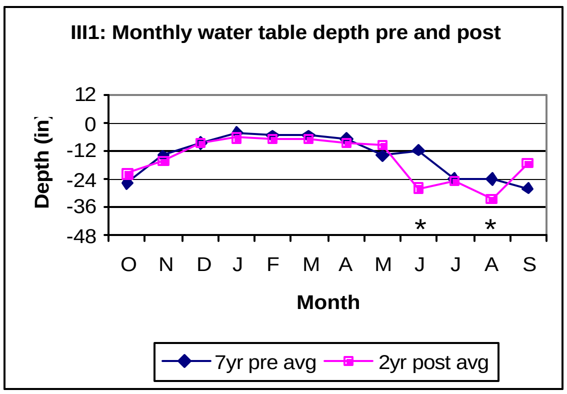


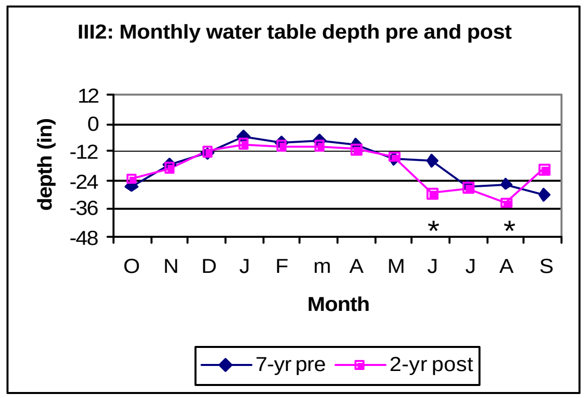


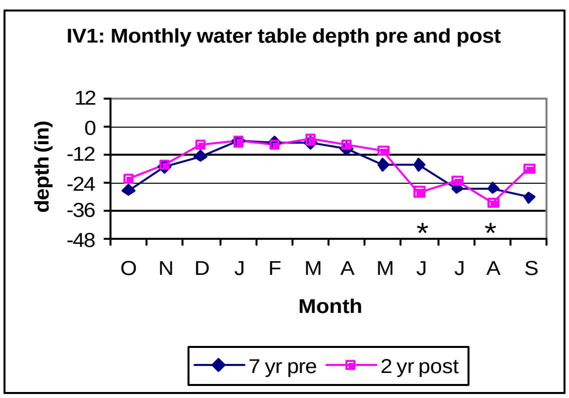
Appendix C1b. Six manual wells located on floodplain adjacent to Tulula fen.

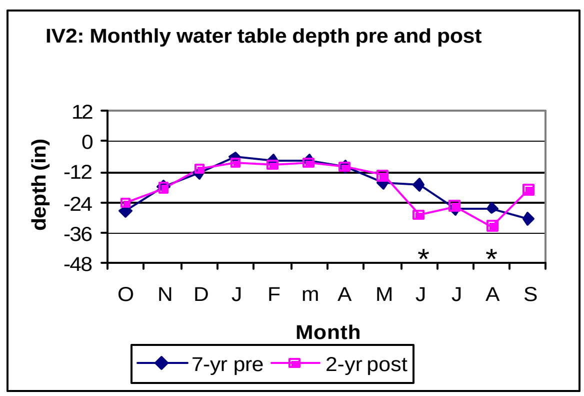




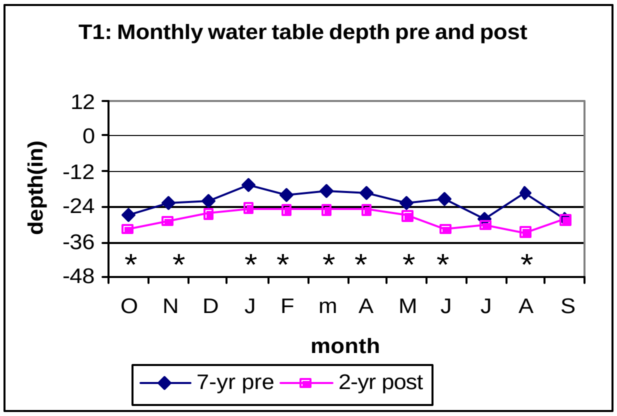


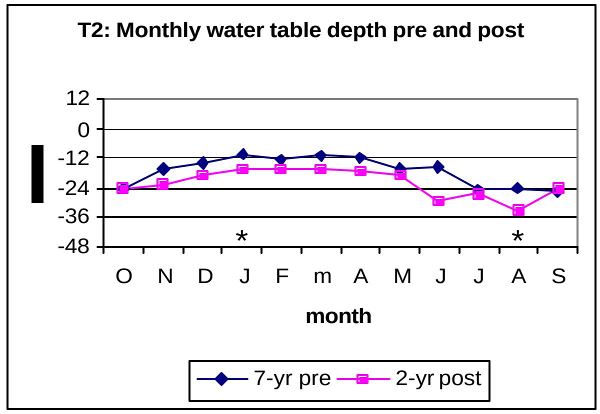


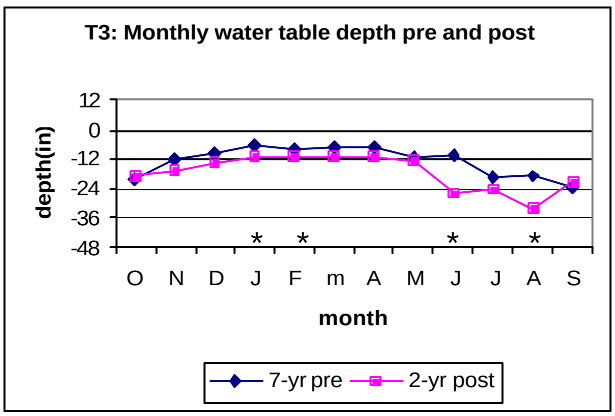


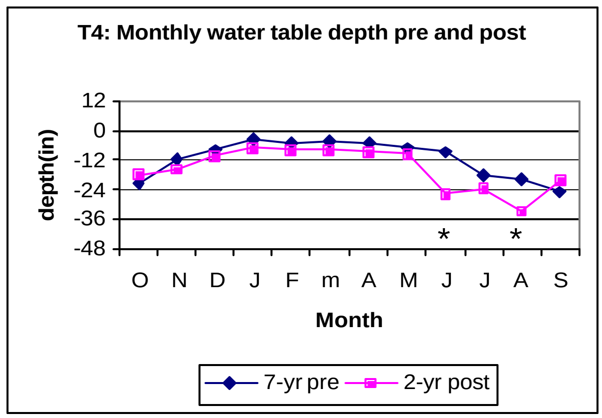


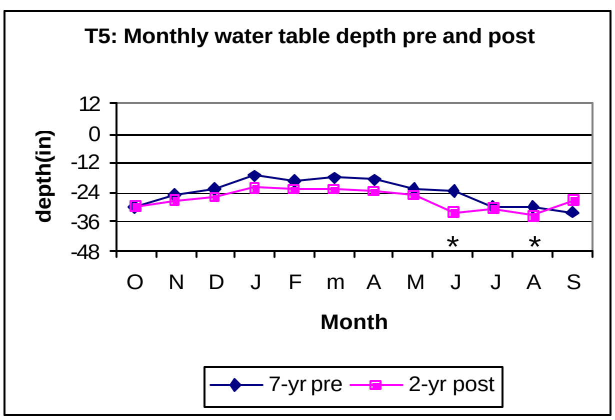
C1c. Transect wells (T-series) located near Tulula Fen.

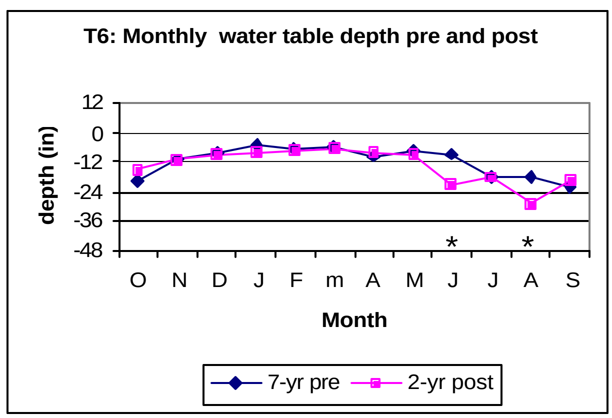


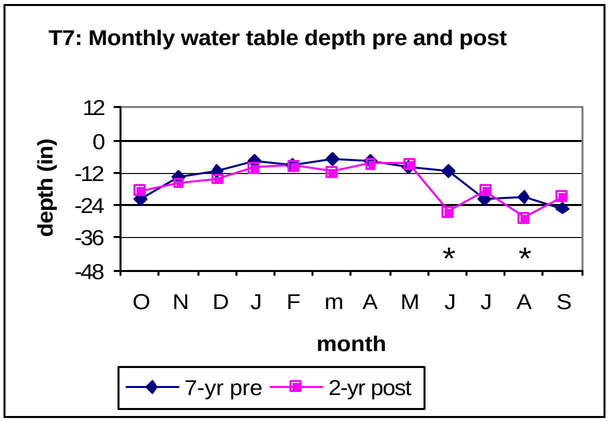


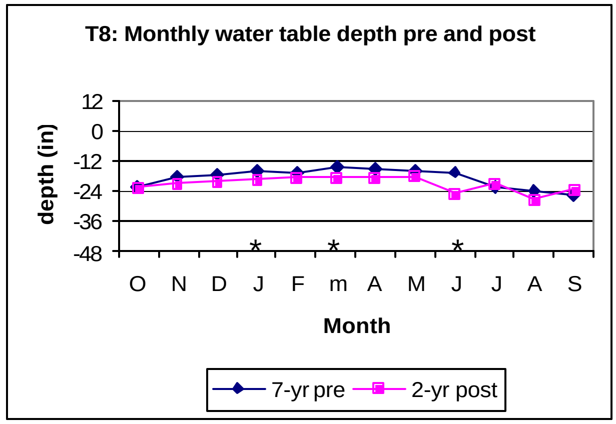


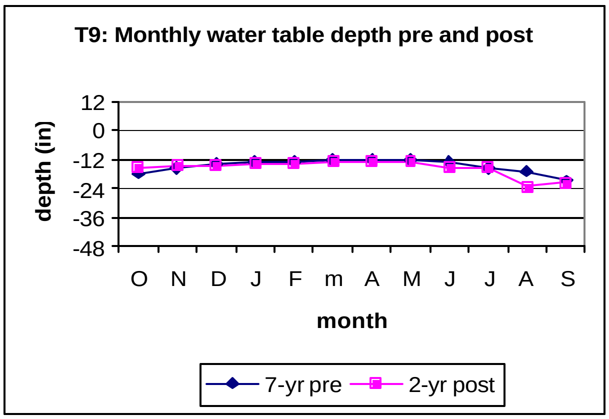


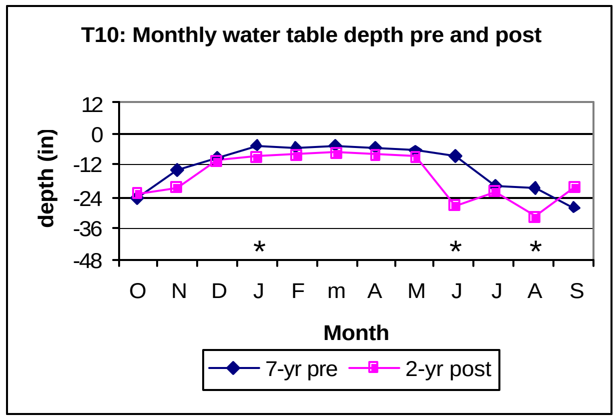


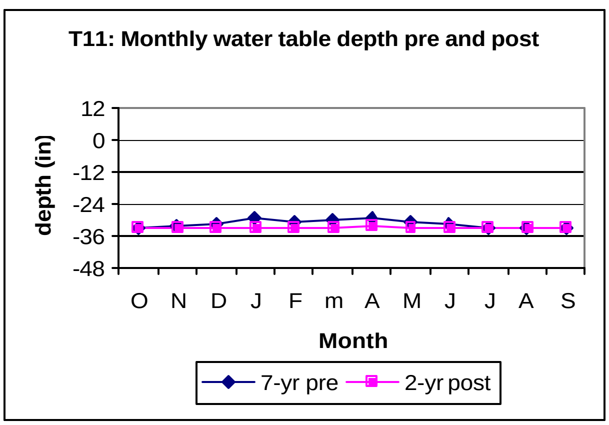


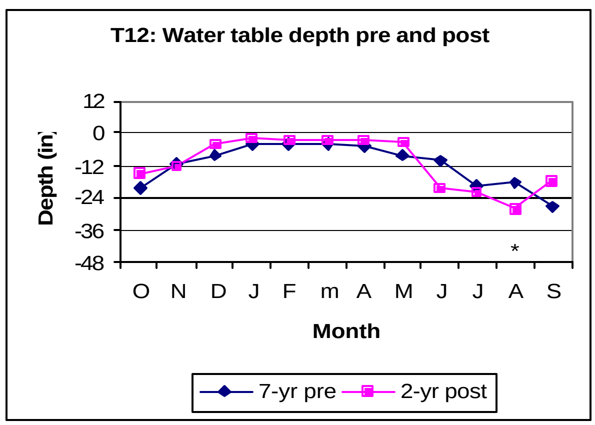

T7: Monthly water table depth pre and post
depth (in)
12
0
-12
-24
-36
-48
*
*
O N D J F m A M J J A S
month
7-yr pre
2-yr post

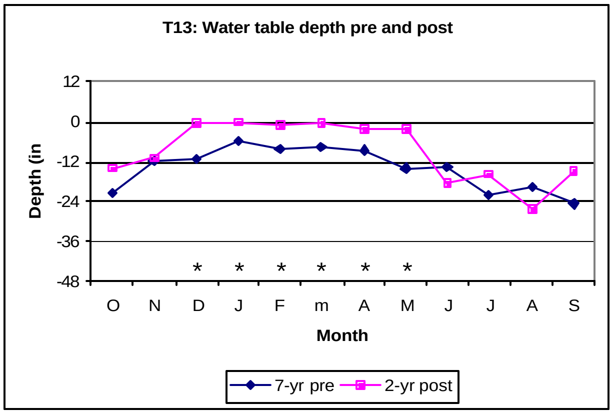

T8: Monthly water table depth pre and post
depth (in)
12
0
-12
-24
-36
-48
*
*
*
O N D J F m A M J J A S
Month
7-yr pre
2-yr post

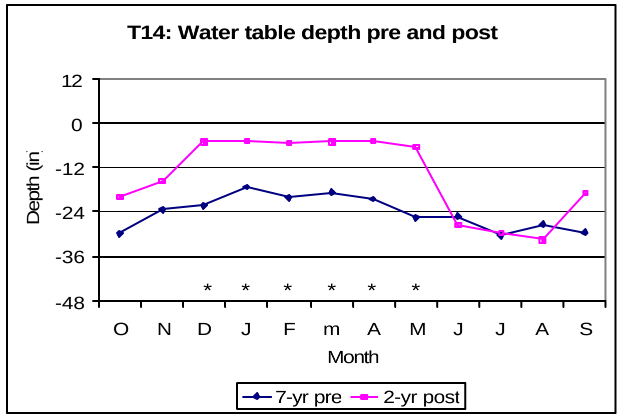

T9: Monthly water table depth pre and post
depth (in)
12
0
-12
-24
-36
-48
O N D J F m A M J J A S
month
7-yr pre
2-yr post


T10: Monthly water table depth pre and post
depth (in)
12
0
-12
-24
-36
-48
*
*
*
O N D J F m A M J J A S
Month
7-yr pre
2-yr post


T11: Monthly water table depth pre and post
depth (in)
12
0
-12
-24
-36
-48
O N D J F m A M J J A S
Month
7-yr pre
2-yr post


T12: Water table depth pre and post
Depth (in)
12
0
-12
-24
-36
-48
*
O N D J F m A M J J A S
Month
7-yr pre
2-yr post


T13: Water table depth pre and post
12
0
-12
-24
-36
-48
Depth (in
* * * * * *
O N D J F m A M J J A S
Month
7-yr pre
2-yr post


T14: Water table depth pre and post
12
0
-12
-24
-36
-48
Depth (in)
* * * * * *
O N D J F m A M J J A S
Month
7-yr pre
2-yr post

APPENDIX D. Amphibian and Reptile species at Tulula

Common Name	Scientific name
Family Ambystomatidae	
spotted salamander	*Ambystoma maculatum*
Family Plethodontidae	
four-toed salamander	*Hemidactylium scutatum*
Ocoee salamander	*Desmognathus ocoee*
black-bellied salamander	*D. quadramaculatus*
Blue Ridge two-lined salamander	*Eurycea bislineata wilderae (= E. wilderae)*
three-lined salamander	*E. guttolineata*
black-chinned red salamander	*Pseudotriton ruber schencki*
Blue Ridge spring salamander	*Gyrinophilus porphyriticus danielsi*
southern Appalachian salamander	*Plethodon oconaluftee*
southern red-backed salamander	*Plethodon serratus*
Family Salamandridae	
red-spotted newt	*Notophthalmus v. viridescens*
Family Bufonidae	
American toad	*Bufo a. americanus*
Family Ranidae	
bullfrog	*Rana catesbeiana*
green frog	*Rana clamitans melanota*
wood frog	*Rana sylvatica*
Family Hylidae	
northern spring peeper	*Pseudacris c. crucifer*
gray treefrog	*Hyla chrysoscelis*
--------------------	--------------------
Family Chelydridae	
common snapping turtle	*Chelydra s. serpentina*
Family Emydidae	
bog turtle	*Clemmys muhlenbergii*
eastern box turtle	*Terrepene c. carolina*
Family Iguanidae (Phyrynosomatidae)	
eastern fence lizard	*Sceloporus u. undulatus*
Family Scincidae	
five-lined skink	*Eumeces fasciatus*
Family Colubridae	
northern water snake	*Nerodia s. sipedon*
eastern garter snake	*Thamnophis s. sirtalis*
eastern ribbon snake	*Thamnophis s. sauritis*
northern ringneck snake	*Diadophis punctatus edwardsii*
black rat snake	*Elaphe o. obsoleta*
northern black racer	*Coluber c. constrictor*
Family Viperidae	
timber rattlesnake	*Crotalus horridus*
northern copperhead	*Agkistrodon contortrix mokasen*

APPENDIX E. Bird Species at Tulula Wetland (1994-2002).

(1) Probably breeding. (4) Foraging, but not breeding.
(2) Nest found. (5) Winter resident.
(3) Migrant.

Common Name	Scientific Name
Family Ardeidae (herons and bitterns)	
Great Blue Heron (4)	*Ardea herodias*
Green Heron (4)	*Butorides striatus*
Family Anatidae (waterfowl)	
Wood Duck (4)	*Aix sponsa*
Family Cathartidae (American vultures)	
Black Vulture (4)	*Coragyps atratus*
Turkey Vulture (4)	*Cathartes aura*
Family Accipitridae (hawks)	
Red-tailed Hawk (4)	*Buteo jamaicensis*
Red-shouldered Hawk (4)	*Buteo lineatus*
Broad-winged Hawk (2)	*Buteo platypterus*
Cooper's Hawk (4)	*Accipiter cooperii*
Family Pandionidae (ospreys)	
Osprey (3)	*Pandion haliaetus*
Family Strigidae (typical owls)	
Eastern Screech Owl (4)	*Otus asio*
Barred Owl (4)	*Strix varia*
Great Horned Owl (2)	*Bubo virginianus*
Family Tetraonidae (grouse)	
Ruffed Grouse (4)	*Bonasa umbellus*
Family Phasianidae (quail, pheasants, etc.)	
Northern Bobwhite (1)	*Colinus virginianus*
Family Meleagrididae (turkeys)	
Wild Turkey (2)	*Meleagris gallopavo*
Family Scolopacidae (sandpipers)	
American Woodcock (1)	*Scolopax minor*
Common Snipe (4)	*Capella gallinago*
Solitary Sandpiper (3)	*Tringa solitaria*
Spotted Sandpiper (3)	*Actitis macularia*
Family Columbidae (pigeons and doves)	
Mourning Dove (1)	*Zenaida macroura*
Family Cululidae (cuckoos)	
Yellow-billed Cuckoo (4)	*Coccyzus americanus*
Black-billed Cuckoo (3)	*Coccyzus erythropthalmus*
Family Caprimulgidae (goatsuckers)	
Whip-poor-will (1)	*Caprimulgus vociferus*
Family Apodidae (swifts)	
Chimney Swift (4)	*Chaetura pelagica*
Family Trochilidae (hummingbirds)	
Ruby-throated Hummingbird (2)	*Archilochus colubris*
Family Alcedinidae (kingfishers)	
Belted Kingfisher (4)	*Ceryle alcyon*

Family Picidae (woodpeckers)

Northern Flicker (2) *Colaptes auratus*
Pileated Woodpecker (4) *Dryocopus pileatus*
Hairy Woodpecker (4) *Picoides villosus*
Downy Woodpecker (1) *Picoides pubescens*

Family Tyrannidae (flycatchers)

Acadian Flycatcher (1) *Empidonax virescens*
Alder Flycatcher (3) *Empidonax alnorum*
Eastern Pewee (1) *Contopus virens*
Eastern Phoebe (1) *Sayornis phoebe*
Eastern Wood-pewee (1) *Contopus virens*

Family Hirundinidae (swallows)

Northern Rough-winged Swallow (4) *Stelgidopteryx serripennis*
Tree Swallow (4) *Tachycineta bicolor*
Barn Swallow (4) *Hirundo rustica*

Family Corvidae (jays and crows)

Blue Jay (1) *Cyanocitta cristata*
Common Raven (4) *Corvus corax*
American Crow (4) *Corvus brachyrhynchos*

Family Paridae (titmice)

Carolina Chickadee (1) *Parus carolinensis*
Tufted Titmouse (1) *Parus bicolor*

Family Sittidae (nuthatches)

White-breasted Nuthatch (1) *Sitta carolinensis*
Red-breasted Nuthatch (3) *Sitta canadensis*

Family Certhiidae (creepers)

Brown Creeper (4) *Certhia americana*

Family Troglodytidae (wrens)

Carolina Wren (1) *Thryothorus ludovicianus*
Winter Wren (3) *Troglodytes troglodytes*

Family Mimidae (mockingbirds, catbirds, thrashers)

Gray Catbird (1) *Dumetella carolinensis*
Brown Thrasher (1) *Toxostoma rufum*

Family Turdidae (thrushes)

American Robin (1) *Turdus migratorius*
Hermit Thrush (3) *Catharus guttatus*
Wood Thrush (1) *Hylocichla mustelina*

Family Sylviidae (kinglets, etc.)

Blue-gray Gnatcatcher (2) *Polioptila caerulea*
Golden-crowned Kinglet (3) *Regulus satrapa*
Ruby-crowned Kinglet (3) *Regulus calendula*

Family Bombycillidae (waxwings)

Cedar Waxwing (1) *Bombycilla cedrorum*

Family Virionidae (vireos)

White-eyed Vireo (1) *Vireo griseus*
Yellow-throated Vireo (1) *Vireo flavifrons*
Solitary Vireo (1) *Vireo solitarius*
Red-eyed Vireo (1) *Vireo olivaceus*

Family Parulidae (wood warblers)	
Black-and-white Warbler (1)	*Mniotilta varia*
Swainson's Warbler (1)	*Limnothlypis swainsonii*
Worm-eating Warbler (3)	*Helmitheros vermivorus*
Golden-winged Warbler (1)	*Vermivora chrysoptera*
Blue-winged Warbler (3)	*Vermivora pinus*
Northern Parula (2)	*Parula americana*
Pine Warbler (1)	*Dendroica pinus*
Black-throated Blue Warbler (3)	*Dendroica caerulescens*
Black-throated Green Warbler (3)	*Dendorica virens*
Yellow-throated Warbler (1)	*Dendroica dominica*
Chestnut-sided Warbler (1)	*Dendroica pensylvania*
Yellow Warbler (3)	*Dendroica petechia*
Ovenbird (2)	*Seiurus aurocapillus*
Kentucky Warbler (2)	*Oporornis formosus*
Common Yellowthroat (1)	*Geothlypis trichas*
Yellow-breasted Chat (1)	*Icteria virens*
Canada Warbler (3)	*Wilsonia canadensis*
Hooded Warbler (2)	*Wilsonia citrina*
American Redstart (3)	*Setophaga ruticilla*
Prairie Warbler (1)	*Dendroica discolor*
Family Icteridae (blackbirds)	
Common Grackle (1)	*Quiscalus quiscula*
Red-winged Blackbird (4)	*Agelaius phoenicus*
Brown-headed Cowbird (1)	*Molothrus ater*
Family Traupidae (tanagers)	
Scarlet Tanager (1)	*Piranga olivacea*
Family Fringillidae (finches, etc.)	
Northern Cardinal (1)	*Cardinalis cardinalis*
Indigo Bunting (2)	*Passerina cyanea*
Blue Grosbeak (3)	*Guiraca caerulea*
American Goldfinch (1)	*Carduelis tristis*
Rufous-sided Towhee (2)	*Pipilo erythrophthalmus*
Northern Junco (5)	*Junco hyemalis*
White-throated Sparrow (5)	*Zonotrichia albicollis*
Field Sparrow (3)	*Spizella pusilla*
Fox Sparrow (3)	*Passerella iliaca*
Swamp Sparrow (5)	*Melospiza georgiana*
Song Sparrow (1)	*Melospiza melodia*